SCIENTIFIC DIALOGUES.

INTENDED FOR THE

INSTRUCTION AND ENTERTAINMENT

OF

YOUNG PEOPLE:

IN WHICH

THE FIRST PRINCIPLES

OF

Natural and Experimental Philosophy

ARE FULLY EXPLAINED.

VOL. II. OF HYDROSTATICS, AND PNEUMATICS.

"Conversation, with the habit of explaining the meaning of words "and the structure of common domestic implements to children, is "the sure and effectual method of preparing the mind for the acquirement of science." *Edgeworth's Practical Education.*

BY THE REV. J. JOYCE.

NEW EDITION CORRECTED AND IMPROVED.

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TO

MARIA EDGEWORTH,

AND

RICHARD LOVELL EDGEWORTH,

F.R.S. AND M.R.I.A.

AUTHORS

OF

PRACTICAL EDUCATION,

THE

SECOND VOLUME

OF

SCIENTIFIC DIALOGUES.

IS RESPECTFULLY INSCRIBED

BY

THE AUTHOR.

June 21. 1802.

Perhaps in that part of the third volume which respects the specific gravities of bodies, the arithmetical operations, though rendered as familiar as the nature of the subject will admit of, may be deemed less easy than the other parts. To those young persons, however, who have studied the subject of decimals, which is by no means a difficult part of arithmetic, no obstacle will present itself, even in the method of obtaining, by experiment and calculation, the specific gravity of any body whetever. In some cases it may be desirable to pass over this part of the book till the reader be a little more grounded in arithmetical operations; but it would have been inexcusable in the author to have omitted it in his plan. The subject is important, and when understood, it will be found not less interesting than the other parts of the work. Authors in general have not illustrated this branch of Hydrostatics in a manner suited to the apprehension of young persons; and, on that account, it will be found discussed much at large in the Scientific Dialogues.

It is hoped that the explanations of all the Hydrostatic and Pneumatic Engines are perfectly adapted to the understanding of those for whom this course of instruction is intended: that they are, in almost all cases, treated in a manner more familiar than has hitherto been attempted, will not, it is presumed, be denied. The author, in proof of this assertion, might, if he were inclined to mention particular instances, refer to the illustrations of the nature and principles of the Hydrostatic Paradox and of the echo and steam-engine; but he conceives he may confidently appeal to the judgment and decision of those that are accustomed to teach these branches of science, with respect to the *whole* of the volume now presented to the public.

OF HYDROSTATICS.

CONVERSATION I.

INTRODUCTION.

Father—Charles—Emma.

FATHER. In pursuing our course of natural and experimental philosophy, we shall now proceed with that branch of science which is called *Hydrostatics.*

Emma. That is a difficult word? what are we to understand by it?

Father. Almost all the technical terms made use of in science are either Greek, or derived from the Greek Language. The word *hydrostatics* is formed of two Gr

words, which *signify* water, and the science which considers the *weight of bodies*. But hydrostatics, as a branch of natural philosophy, treats of the nature, gravity, pressure, and motion of fluids in general; and of the methods of weighing solids in them.

Charles. Is this an important part of knowledge?

Father. Taken in this extensive sense, it yields to none as to its real importance. And the experiments which I shall show you are curious and highly amusing.

Emma. Shall we be able to repeat them ourselves?

Father. Most of them you will, provided you are very careful in using the instruments, almost all of which are made of glass. I ought to tell you that many writers divide this subject into two distinct parts, viz. *hydrostatics* and *hydraulics*; the latter relates particularly to the motion of water through pipes, conduits, &c.

In these conversations, I shall pay no re-
this distinction, but shall, under the
itle of hydrostatics, describe the

properties of all fluids, but principally those of water; explaining, as we go on, the motions of it, whether in pipes, pumps, siphons, engines of different kinds, fountains, &c. Do you know what a fluid is?

Charles. I know how to distinguish a fluid from a solid: water and wine are fluids, but why they are so called I cannot tell.

Father. A fluid is generally defined as a body, the parts of which readily yield to any impression, and in yielding are easily moved among each other.

Emma. But this definition does not notice the wetting of other bodies brought into contact with a fluid. If I put my fingers into water or milk, a part of it adheres to them, and they are said to be wet.

Father. Every accurate definition must mark the qualities of all the individual things defined by it: now there are many fluids which have not the property of wetting the hand when plunged into them. The air we breathe is a fluid, the parts of which yield to the least pressure, but it does not

adhere to the bodies surrounded by it like water.

Emma. Air, however, is so different from water, that, in this respect, they will scarcely admit of comparison.

Charles. I have sometimes dipped my finger into a cup of quicksilver, but none of the fluid came away with it.

Father. You are right; and hence you will find that some writers on natural philosophy distinguish between fluids and liquids. Air, quicksilver, and melted metals, are fluids, but not liquids: while water, milk, beer, wine, oil, spirits, &c. are fluids and liquids.

Charles. Are we then to understand, that liquids are known by the property of adhering to different substances which are immersed in them?

Father. This description will not always hold; for though mercury will not stick to your hand if plunged into a cup of it, yet it will adhere to many metals, as tin, gold, &c. The distinction between liquids and fluids is introduced into books more on account

of common convenience, than philosophical accuracy: the liquid is distinguished by the cohesion of its particles with each other*.

Emma. You said, I believe, that a fluid is defined as a body, whose parts yield to the smallest force impressed.

Father. This is the definition of a perfect fluid; and the less force that is required to move the parts of a fluid, the more perfect is that fluid.

Charles. But how do people reason respecting the particles of which fluids are composed? have they ever seen them?

Father. Philosophers imagine they must be exceedingly small, because with their best glasses they have never been able to discern them. And they contend that these particles must be round and smooth, since they are so easily moved among and over one another. If they are round, you know, there must be vacant spaces left between them.

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* See Note[a], p. 20.

Emma. How is that, Papa?

Father. Suppose a number of cannon balls were placed in a large tub, or any other vessel (Plate 1. Fig. 1.), so as to fill it up even with the edge: though the vessel would contain no more of these large balls, yet it would hold in the vacant spaces a great many smaller shot: and between these, others still smaller might be introduced: and when the vessel would contain no more small shot, a great quantity of sand might be shaken in, and, between the pores of these, water or other fluids would readily insinuate themseleves.

Emma. This I understand; but are there any other proofs that water is made up of such globular particles?

Father. There are several;—all aquatic plants, that is, plants which live in water, are said to have their pores round, and are thereby adapted to receive the same shaped particles of water: all mineral and medicinal waters evidently derive their peculiar character from the different substances taken

into their pores; from which it has been concluded, that the particle of water are globular, because such admit of the largest intervals.

Upon this principle tinctures, as those of bark, rhubarb, &c. are made: a quantity of the powder of bark, or any other substance, is put into spirits of wine, the very fine particles are taken into the pores of the spirit: these change the colour of the mass, though it remains as transparent as it was before.

Charles. But in these cases, is not the bulk of the fluid increased?

Father. In some instances it is, but in others the bulk will remain precisely the same, as the following very easy experiment will show.

Take a phial with some rain water, mark very accurately the height at which the water stands in the bottle, after which you may introduce a small quantity of salt, which, when completely dissolved, you will find has not in the least increased the bulk of the water. When the salt is taken up,

sugar may be dissolved in the water without making any addition to its bulk.

Emma. Are we then to infer, that the particles of salt are smaller than those of water, and lie between them as the small shot lie between the cannonballs; and that the particles of sugar are finer than those of salt, and, like the sand among the shot, will insinuate themselves into vacuities too small for the admission ofthe salt?

Father. I think the experiment fairly leads to that conclusion. Another fact respecting the particles of fluids deserving your notice is, that they are exceedingly hard, and almost incapable of compression?

Charles. What do you mean, Sir, by compression?

Father. I mean the act of squeezing any thing, in order to bring its parts nearer together. Almost all substances with which we are acquainted may, by means of pressure, be reduced into a less space than they naturally occupy. But water, oil, spirits, quicksilver, &c. cannot, by any pres-

sure of which human art or power is capable, be reduced into a space *sensibly* less than they naturally possess.

Emma. Has the trial ever been made?

Father. Yes, by some of the ablest philosophers that ever lived. And it has been found, that water will find its way through the pores of gold even, rather than suffer itself to be compressed into a smaller space.

Charles. How was the experiment made?

Father. At Florence, a celebrated city in Italy, a globe made of gold was filled with water, and closed so accurately that none of it could escape. The globe was then put into a press, and a little flattened at the sides: the consequence of which was, that the water came through the fine pores of the golden globe, and stood upon its surface like drops of dew.

Charles. Would not the globe contain as much after its sides were bent in as it did before?

Father. It would not; and as the water forced its way through the gold rather than

suffer itself to be brought into a smaller space than it naturally occupied, it was concluded at that time, that water was incompressible. Later experiments have, however, shown, that those fluids which were esteemed incompressible, are, in a very small degree, as, perhaps, one part in twenty thousand, capable of compression.

Emma. Is it on this account you conclude that the particles are very hard?

Father. Undoubtedly: for if they were not so, you can easily conceive, that since there are vacuities between them as we have shown, and as are represented in Fig. 1. they must by very great pressure be brought closer together, and would *evidently* occupy a less space, which is contrary to fact.

NOTE.—Water, oil, spirits, &c. are said to be incompressible, not because they are absolutely so, but because their compressibility is so very small as to make no sensible difference in calculations relative to the several properties of those fluids.

Mr. Canton discovered the compressibility of water in the year 1761, and he says, that from repeated trials he found that water will expand, and rise in a tube, by removing the weight of the atmosphere, about one part

in 21,740, and will be as much compressed under the weight of an additional atmosphere.—*Phil. Trans.* Vol. LII.

* A fluid that has no immediate tendency to expand when at liberty, is commonly considered as a liquid, as water, oil, &c. See young's Lectures, Vol. I. p. 259.

CONVERSATION II.

Of the Weight and Pressure of Fluids.

FATHER. In our last conversation we considered the nature of the component parts of fluids: I must now tell you, that these parts or particles act, with respect to their weight or pressure, independently of each other.

Emma. Will you explain what you mean by this?

Father. You recollect, that, by the attraction of cohesion*, the parts of all solid substances are kept together, and press into one common mass. If I cut a part of this wooden ruler away, the rest will remain in pre-

* See Vol. I. Of Mechanics. Conver. III.

cisely the same situation as it was before. But if I take some water out of the middle of a vessel, the remainder flows instantly into the place from whence that was taken, so as to bring the whole mass to a level.

Charles. Have the particles of water no attraction for each other?

Father. Yes, in a slight degree. The globules of dew* on cabbage plants prove, that the particles of water have a greater attraction to one another, than they have to the leaf on which they stand. Nevertheless, this attraction is very small, and you can easily conceive, that if the particles are round they will touch each other in very few parts, and slide with the smallest pressure. Imagine that a few of the little globules were taken out of the vessel (Fig. 1.), and it is evident that the surrounding ones would fall into their place. It is upon this principle that the surface of every fluid, when at rest, is horizontal or level.

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* See Vol. I. Of Mechanics. Conver. IV.

Charles. Is it upon this principle that water-levels are constructed?

Father. It is: the most simple kind of water-level is a long wooden trough, which being filled to a certain height with water, its surface shows the level of the place on which it stands.

Charles. I did not allude to this kind of levels, but to those smaller ones contained in glass tubes.

Father. These are, more properly speaking, air-levels. They are thus constructed (Plate I. Fig. 2.): D is a glass tube fixed into L, a socket made generally of brass. The glass is filled with water, or some other fluid, in which is enclosed a single bubble of air. When this bubble fixes itself at the mark *a*, made exactly in the middle of the tube, the place on which the instrument stands is perfectly level. When it is not level, the bubble will rise to the higher end.

Emma. What is the use of these levels?

Father. They are fixed to a variety of ophical instruments, such as quadrants,

and telescopes for surveying the heavens; and theodolites for taking the level of any part of the earth. They are also useful in the more common occurrences of life. A single instance will show their value: clocks will not keep true time unless they stand very upright; now by means of one of those levels you may easily ascertain whether the bracket, upon which the clock in the passage stands, is level.

Emma. But I remember when Mr. F—— brought home your clock, he tried if the bracket was even by means of one of Charles's marbles. How did he know by this?

Father. The marble, being round, touched the board in a point only, consequently the line of direction* could not fall through that point, but the marble would roll; unless the bracket was very level; therefore, when the marble was placed in two or more

* See Vol. I. Of Mechanics. Conver. IX.

different parts of the board, and did not move to one side or the other, he might safely conclude that it was level.

Charles. Then the water-level and the rolling of the marble depend on the same principle?

Father. They do, upon the supposition that the particles of water are round. The water-level will, however, be the most accurate, because we may imagine that the parts of which water is composed are perfectly round, and, therefore, as may be geometrically proved, they will touch only in an infinitely small point; whereas, marbles made by human contrivance, touch in many such points.

We now come to another very curious principle in this branch of science, viz. *that fluids press equally in all directions.* All bodies, both fluid and solid, press downwards by the force of gravitation, but fluids of all kind exert a pressure upwards and sideways equal to their pressure downwards.

Emma. Can you show any experiments in proof of this?

Father, A, B, C (Plate 1. Fig. 3.), is a bended glass tube: with a small glass funnel (Plate 1. Fig. 4.) pour in the mouth A, a quantity of sand. You will find that, when the bottom part is filled, whatever is poured in afterwards will stand in the side of the tube A B, and not rise in the other side B C.

Charles. The reason of this is, that by the attraction of gravitation all bodies have a tendency to the earth*; that is, in this case, to the lowest part of the tube; but if the sand ascended in the side B C, its motion would be directly the reverse of this principle.

Father. You mean to say that the pressure would be upwards, or *from* the centre of the earth.

Charles. It certainly would.

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* See Vol. I. Of Mechanics. Conver. V.

Father. Well, we will pour away the sand and put water in its place: what do you say to this?

Emma. The water is level in both sides of the tube.

Father. This then proves, that with respect to fluids there is a pressure upwards at the point B as well as downwards. I will show you another experiment.

A B (Plate I. Fig. 5.) is a large tube or jar having a flat bottom: *a b* is a smaller tube open at both ends. While I fill the jar with water, I take care to hold the small tube so close to the bottom of the jar as to prevent any water from getting into the tube. I then raise it a little, and you see it is instantly filled with water from the jar.

Charles. It is: and the water is level in the jar and the tube.

Father. The tube, you saw, was filled by means of the pressure upwards, contrary to its natural gravity.

Take out the tube; now the water hav-

ing escaped, it is filled with air. Stop the upper end *a* with a cork, and plunge it into the jar, the water will only rise as high as *b*.

Emma. What is the reason of this, Papa?

Father. The air with which the tube was filled is a body, and unless the water were first to force it out from the tube, it cannot take its place. While this ink-stand remains here, you are not able to put any other thing in the same part of space.

Charles. If air be a substance, and the tube is filled with it, how can any water make its way into the tube?

Father. This is a very proper question. Air, though a substance, and, as we have already observed, a fluid too, differs from water in this respect, that it is easily compressible; that is, the air, which by the natural pressure of the surrounding atmosphere, fills the tube, may, by the additional upward pressure of the water, be reduced into a smaller space, as *a b*. Another experiment will illustrate the difference between compressible and incompressible fluids.

Fill the tube, which has still a cork in one end, with some coloured liquor, as spirits of wine; over the other end place a piece of pasteboard, held close to the tube, to prevent any of the liquor from escaping: in this way introduce the tube into a vessel of water, keeping it perpendicular all the time: you may now take away the pasteboard, and force the tube to any depth, but the spirit is not like the air, it cannot in this manner be reduced into a space smaller than it originally occupied.

Emma. Why did not the spirits of wine run out of the tube into the water?

Father. Because spirits are lighter than water, and it is a general principle that the lighter fluid always ascends to the top.

Take a thin piece of horn or pasteboard, and while you hold it by the edges, let your brother put a pound weight upon it: what is the result?

Emma. It is almost bent out of my hand.

Father. Introduce it now into a vessel of water at the depth of twelve or fifteen inches, it parallel to the surface. In this

position, it sustains many pounds weight of water.

Charles. Nevertheless it is not bent in the least.

Father. Because the upward pressure against the lower surface of the horn is exactly equal to the pressure downward, or, which is the same thing, it is equal to the weight of the water which it sustains on the upper surface.

You may vary these experiments by yourselves till we meet again: when we shall resume the same subject.

CONVERSATION III.

Of the Weight and Pressure of Fluids.

CHARLES. When you were explaining the principle of the Wheel and Axis,* I asked the reason why, as the bucket ascended near the top of the well, the difficulty in raising it increased? I have just now found another part of the subject beyond my comprehension. After the bucket is filled with water, it sinks to the bottom of the well, or as far as the rope will suffer it; but in drawing it up through the water, it seems to have little or no weight till it has ascended

* Vol. I. Of Mechanics. Conver. XVII.

to the surface of the water. How is this accounted for?

Father. I do not wonder that you have noticed this circumstance as singular. It was long believed by the ancients that water did not gravitate, or had no weight, in water: or, as they used to express it more generally, that fluids do not gravitate *in proprio loco.*

Emma. I do not understand the meaning of these hard words.

Father. Nor would I have made use of them, only that you can scarcely open a treatise on this subject without finding the phrase. I will explain their meaning without translating the words, because a mere translation would give you a very inadequate idea of what the writers intended to express by them.

No one ever doubted that water and other fluids had weight when considered by themselves; but it was supposed that they had no weight when immersed in a fluid of the same kind. The fact which your brother has just mentioned respecting the bucket

was the grand argument upon which they advanced and maintained this doctrine.

Emma. Does it not weigh any thing, then, till it is drawn above the surface?

Father. You must, my little girl, have patience, and you shall see how it is. Here is a glass bottle A (Plate I. Fig. 6.), with a stop-cock B cemented to it, by means of which the air may be exhausted from the bottle, and prevented from returning into it again. The whole is made sufficiently heavy to sink in the vessel of water C D.

The bottle must be weighed in air, that is, in the common method; and suppose it weighs 12 ounces, let it now be put into the situation which is represented by the figure, when the weight of the bottle must be again taken by putting weights into the scale Z. I then open the stop-cock while it is under water, and the water immediately rushes in and fills the bottle, which overpowers the weights in the scale. I now put other weights, say 8 ounces, into the scale, to re-·re the equilibrium between the bottle and :. It is evident, then, that 8 ounces is

the weight of the water in the bottle, while weighed under water. Fasten the cock, and weigh the bottle in the usual way in the air.

Charles. It weighs something more than 20 ounces.

Father. That is 12 ounces for the bottle, and 8 ounces for the water, besides a small allowance to be made for the drops of water that adhere to the outside of the bottle. Does not this experiment prove that the water in the bottle weighed just as much in the jar of water as it weighed in the air?

Emma. I think it does.

Father. Then we are justified in concluding that the water in the bucket, which the bottle may represent, weighed as much while under water in the well, as it did after it was raised above the surface.

Charles. This fact seems decisive, but the difficulty still remains in my mind, for the weight of the bucket is not felt till it is rising above the surface of the water.

Father. It may be thus accounted for: any substance of the same specific gravity

with water, may be plunged into it, and it will remain wherever it is placed, either near the bottom, in the middle, or towards the top, consequently it may be moved in any direction with the application of a very small force.

Emma. What do you mean by the specific gravity of a body?

Father. The *specific gravity* of any body is its weight *compared* with that of any other body.* Hence it is also called the *comparative* gravity: thus if a cubical inch of water be equal in weight to a cubical inch of any particular kind of wood, the specific or comparative gravities of the water and that particular wood are equal. But since a cubical inch of deal is lighter than a cubical inch of water, and water, is lighter than the same bulk of lead or brass, we say the specific gravity of the lead, or brass, is greater than that of water, and the specific gravity of water is greater than that of deal.

* See Conversation X, &c.

Charles. The water in the bucket must be of the same specific gravity with that in the well, because it is a part of it.

Father. And the wooden bucket differs very little in this respect from the water; because, though the wood is lighter, yet the iron of which the hoops and handle are composed is specifically heavier than water; so that the bucket and water are nearly of the same specific gravity with the water in the well, and therefore it is moved very easily through it.

Again, we have already proved that the upward pressure of fluids is equal to the pressure downwards, therefore the pressure at the bottom of the bucket upwards being precisely equal to the same force in a contrary direction, the application of a very small force, in addition to the upward pressure, will cause the bucket to ascend.

Emma. You account for the easy ascent of the bucket upon the same principle by which you have shown that horn or pastboard will not be bent, when placed horizontally at any depth of water?

Father. It is: for when a cask is full, and perfectly close, there is no downward pressure, and therefore the air pressing against the mouth of the cock keeps the liquor from running out; a hole made at the top of the cask admits the external pressure of the air, by which the liquor is forced out. In large casks of ale or porter, where the demand is not very great, the vent-hole need seldom be used, for a certain portion of the air contained in the liquor escapes, and being lighter than the beer, ascends to the top, by which a pressure is created without the assistance of the external air.

CONVERSATION IV.

Of the lateral Pressure of Fluids.

FATHER. It is time now to advance another step in this science, and to show you that the *lateral*, or *side* pressure, is equal to the perpendicular pressure.

Emma. If the upward pressure, is equal to the downward, and the side pressure is also equal to it, then the pressure is equal in all directions.

Father. You are right. Though the side direction may be varied in many ways, yet there are only the upward, downward, and lateral directions. The two former we have shown are equal. That the side pressure is equal to the perpendicular pressure down-

wards, is demonstrated by a very easy experiment.

A B (Plate I. Fig. 7.) is a vessel filled with water, having two equal orifices or holes, *a*, *b*, bored with the same tool, one at the side, and the other in the bottom: if these holes are opened at the same instant, and the water suffered to run into two glasses, it will be found that, at the end of a given time, they will have discharged equal quantities of water; which is a clear proof that the water presses side-wise as forcibly as it does downwards.

Charles. Are we then to take it as a general principle that fluids press in every possible direction?

Father. This, I think, our experiments have proved: but you must not forget that it is only true upon the supposition that *the perpendicular heights are equal*. For in the last experiment, if the hole *b* had been bored an inch or two higher in the side of the vessel, as at *c*, the quantity of water
out at *a* would have been greater
at *b*; and much greater would it

have been, if the hole had been bored at four or five inches above the bottom of the vessel.

This subject of pressure may be farther illustrated. At the bottom of this tube *z y* (Plate 1. Fig. 8.), open at both ends, I have tied a piece of bladder, and have poured in water till it stands at the mark *x*. Owing to the pressure of the water, the bladder is convex, that is, bent outwards; dip it into the jar (Fig. 5.), the bladder is still convex: thrust it gently down, the surface of the water in the tube is now even with that in the jar.

Emma. It is; and the bladder at the bottom is become flat.

Father. The perpendicular depths being equal, the pressure upward is equal to that downwards, and the water in the tube is exactly balanced by the water in the jar. Let the tube be thrust deeper into the water.

Charles. Now the bladder is bent upwards.

Father. The upward pressure is estimat-

ed by the perpendicular depth of the water in the jar, measured from the surface to the bottom of the tube: but the pressure downwards must be estimated by the perpendicular height of the water in the tube, which being less than the former, the pressure upward in the same proportion overcomes that downwards, and forces up the bladder into the position as you see it. This and the following experiment are some of the best that can be exhibited in proof of the upward pressure of fluids.

Dip an open end of a tube, having a very narrow bore, into a vessel of quicksilver; then stopping the upper orifice with the finger, lift up the tube out of the vessel, and you will see a sort of column of quicksilver hanging at the lower end, which, when dipped in water lower than 14 times its own length, will, upon removing the finger, be pressed upwards into the tube.

Emma. Why do you fix upon 14 times the depth?

[illegible] Because quicksilver is 14 times

heavier than water. Upon this principle of the upward pressure, lead or any other metal may be made to swim in water. A B (Plate I. Fig. 9.) is a vessel of water, and *a b* is a glass tube open throughout, *d* is a string by which a flat piece of lead *x* may be held fast to the bottom of the tube. To prevent the water from getting in between the lead and the glass, a piece of wet leather is first put over the lead.

In this situation, let the tube be immersed in the vessel of water, and if it be plunged to the depth of about eleven times the thickness of the lead before the string be let go, the lead will not fall from the tube, but be kept adhering to it by the upward pressure below it.

Emma. Is lead 11 times heavier than water?

Father. It is between 11 and 12 times heavier; and therefore to make the experiment sure, the tube should be plunged somewhat deeper than 11 times the thickness of the lead.

Charles. Is it not owing to the wet leather that the lead sticks to the tube, rather than to the upward pressure?

Father. If that be the case, it will remain fixed if I draw up the tube an inch or two higher:—I will try it.

Emma. It has fallen off.

Father. Because when the tube was raised, the upward pressure was diminished so much as to become too small to balance the weight of the lead. But if the adhering together of the lead and tube had been caused by the leather, there would be no reason why it should not operate the same at six or nine times the depth of the lead's thickness, as well as at 11 or 12 times that thickness.

This last experiment is neatly described by Mr. Capel Lofft in the following lines:

———And since on every side
The fluid presses with an equal force
Proportion'd to the column of its height,

The yielding water may be made to buoy
Or *lead* or *gold*, if, artfully, so much
Be made to float above the weight immers'd,
As, in proportion to the mass entire,
Equals the difference of gravity
Between the *fluid* and the *solid* mass.

EUDOSIA.

CONVERSATION V.

Of the Hydrostatical Paradox.

Emma. You are to explain a paradox to day: I thought natural philosophy had excluded all paradoxes.

Father. Dr. Johnson has given this definition of a paradox, "an assertion contrary to appearances:" now the assertion which I am to refer you to is, *that any quantity of water, however small, may be made to balance and support any quantity, however large.* That a pound of water, for instance, should, without any mechanical advantage, be made to support ten ··nds, or a hundred, or even a ton weight, ·s at first incredible; certainly it is

contrary to what one should expect, and on that account the experiment to show this fact has usually been called the hydrostatical paradox.

Charles. It does appear unaccountable: I hope the experiments may be very easy to be understood.

Father. Many have been invented for the purpose, but I know of none better than those described by Mr. Ferguson in his lectures on select subjects.

O B G H (Plate II. Fig. 10.) is a glass vessel, consisting of two tubes of very different sizes, joined together, and freely communicating with one another. Let water be poured in at H, which will pass through the joining of the tubes, and rise in the wide one to the same height exactly as it stands in the smaller; which shows that the small column of water in D G balances the large one in the other tube. This will be the case if the quantity of water in the small tube be a thousand or a million of times less than the quantity in the larger one.

If the smaller tube be bent in any oblique, situation, at G F, the water will stand at F, that is, on the same level as it stands at A. This would be the case, if instead of two tubes there were any given number of them connected together at B, and varied in all kinds of oblique directions, the water would be on a level in them all; that is, the *perpendicular height* of the water would be the same.

Charles. This does not quite satisfy me; because it appears that a great part of the water in the large tube is supported by the parts B about the bottom, and therefore that the water in the smaller tube only sustains the pressure of a column of water, the diameter of which is equal to its own diameter.

Father. This would be the case if the pressure of fluids were only downwards, but we have shown that it acts in all directions: and therefore the pressure of the parts near the side of the tube acts against the column in the middle, which you sup- the only part of the water sus-

tained by that which is contained in the small tube, consequently the smaller quantity of water in D B sustains the larger one in A B.

Let us try another experiment.

A B C and A B C, (Plate II. Figs. 11 and 12.) are two vessels, having their bottoms D d and D d exactly equal, but the contents of one vessel is twenty times greater than the other; that is, Fig. 11, when filled up to A, will hold but one pint of water, whereas Fig. 12, when filled to the same height, will hold twenty pints. Brass bottoms, C, C, are fitted exactly to each vessel, and made water-tight by pieces of wet leather. Each bottom is joined to its vessel by a hinge D, so that it opens downwards, like the lid of a box. By means of a little hook *d*, a pulley F, and a weight E, the bottom is kept close to the vessel, and will hold a certain quantity of water.

Emma. That is, till the *weight* of the water overcome the weight E.

Father. I should rather say, till the

pressure of the water overcome the weight E.

Now hold the vessel (Fig. 12.) upright in your hands, while I gradually pour water into it with a funnel; the pressure bears down the bottom, and, of course, raises the weight, and a small quantity of the water escapes. Let us mark the height H A, at which the surface of the water stood in the vessel when the bottom began to give way.

Try the other vessel (Fig. 11.) in the same manner, and we shall see that when the water rises to A, that is, to just the same height in this vessel as in the former, the bottom will also give way, as it did in the other case. Thus equal weights are overcome in the one case by twenty pints of water, and in the other by a single pint. The same would hold good if the difference were greater or less in any given proportion.

Emma. What is the reason of this, Papa?

Father. It depends upon two principles

with which you are acquainted. The first is, that fluids press equally in all directions: and the second is, that action and re-action are equal and contrary to each other.* The water, therefore, below the fixed part B *f*, will press as much upward against the inner surface, by the action of the small column, as it would by a column of the *same height*, and of any other diameter whatsoever: and since action and re-action are equal and contrary, the action against the inner surface B *f* will cause an equal re-action of the water in the cavity B *f* c c against the bottom c, consequently the pressure upon the bottom of Fig. 11. will be as great as it was upon the same part of Fig. 12.

Charles. Can you prove by experiment that there is this upward pressure against the inner surface B *g f*?

Father. Very easily: suppose at *f* there were a little cork, to which a small string

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* See Vol. I. Of Mechanics, Conver. XI.

was fixed: I might place a tube over the cork, and then draw it out, the consequence of which would be, that the water in the vessel would force itself into the tube, and stand as high in it as it does in the vessel. Would not this experiment prove that there was this upward pressure against B *f*?

Charles. It would: and I can easily conceive, that if other tubes were placed in the same manner, in different parts of B *f*, the same effect would be produced.

Father. Then you must admit, that the action against B *f*, or, which is the same thing, the re-action against C, that is, the pressure of the water against the bottom, is equally great as it would be if the vessel were as large in every part as it is at the bottom, and the water stood level to the height A *a*.

Charles. Yes, I do: because if tubes were placed in every part of B *f*, the same effect would be produced in them all, as in the single one at *f*; but if the whole surface were covered with small tubes, there

would then be little or no difference between the two vessels, (Figs. 11 and 12.)

Father. There would be no difference, provided you kept filling the large tube, so that the water should stand in them all at the same level A *a*. Otherwise, the introduction of a single tube *a f* would make a material difference: for though the water in A C would overcome the weight E, yet if with my hand I prevent any of the water from running out till I have taken out the cork, and suffered the water to force itself out of the vessel into the small tube, I may remove my hand with safety; for the water will not overcome the weight now, though there is certainly the same quantity of water in it as there was before the little tube *a f* was inserted.

Emma. I think I see the reason of this: the water stood as high as A *a* before the little tube was introduced, but now it stands at the level *x x*, and you told us yesterday that the pressures were only equal, provided the *perpendicular heights were also equal.*

Father. I am glad to find you so atten-tive to what I say. In order that the pres-sure may overcome the weight E, you must put in more water till it rise to the level A A, and now you see the weight rises, and the water flows out.

I will put another tube at *g*, and the water rushes into that causes the level to descend again to *x x*, and I must put more water in to bring the level up to A *a*, be-fore it can overcome the weight E. What I have shown in these two cases will hold true in all, supposing you fill the cover with tubes.

Charles. I see, then, that it is the dif-ference of the perpendicular heights which causes the difference of pressure, and can now fully comprehend the reason why a pint of water may be made to balance or support a hogshead: or, in the words with which you set out, that any *quantity of wa-ter, however small, may be made to balance and support any other quantity however large.*

Father. It is to this principle in hydrostatics that Mr. Capel Lofft, refers in his work entitled "Eudosia, or a Poem on the Universe:"

> All *homogeneous* fluids, which ascend,
> To equal heights, and join in equal base,
> Balance each other; howsoe'er in form
> Of the containing vessel disagreed,
> Or in the fluid quantity contain'd.

Emma. What does he mean by the word *homogeneous?*

Father. Homogeneous fluids, are fluids of the *same kind.* What has been proved with regard to water, may be shown to hold with regard to wine, or oil, or any other fluid. But the experiment will not answer if different fluids are made use of, as water and oil together.

CONVERSATION VI.

Of the Hydrostatic Bellows.

FATHER. I think we have made it sufficiently clear that the pressure of fluids *of the same kind* is always proportional to the area of the base multiplied into the perpendicular height at which the fluid stands, without any regard to the form of the vessel, or the quantity of fluid contained in it.

Emma. I cannot help saying, that it still appears very mysterious to me, that a pint of water (Fig. 11.) should have an equal pressure with the twenty pints in the next vessel. You will not say that one pint weighs as much as the twenty.

Father. Your objection is proper. The pressure of the water upon the bottom c, c, does not in the least alter the weight of the vessel and water considered as one mass; for the action and re-action, which cause the *pressure*, destroy one another with respect to the *weight* of the vessel, which is as much sustained by the action upwards, as it is pressed by the re-action downwards.

The *pressure* of water and other fluids differs from the gravity or *weight* in this respect; the *weight* is according to the *quantity*; but the pressure is according to the *perpendicular height*.

Charles. Suppose both vessels were filled with any solid substance, would the effect produced be very different?

Father. If the water were changed into ice, for instance, the pressure upon the bottom of the smaller vessel would be much less than that upon the larger.

Here is another instrument (Fig. 13.)

to show you that a very few ounces of water will lift up and sustain a large weight.

Emma. What is the instrument called?

Father. It is made like common bellows, only without valves, and writers have given it the name of the hydrostatic bellows. This small tin-pipe *e o p* communicates with the inside of the bellows. At present the upper and lower board are kept close to one another with the weight *w*. The inside of the boards are not very smooth, so that water may insinuate itself between them: pour this half pint of water into the tube.

Charles. It has separated the boards, and lifted up the weight.

Father. Thus you see that seven or eight ounces of water has raised and continues to sustain a weight of 56 ℔. By diminishing the bore of the pipe, and increasing its length, the same or even a smaller quantity of water would raise a much larger weight.

Charles. How do you find the weight

that can be raised by this small quantity of water?

Father. Fill the bellows with water, the boards of which, when distended, are three inches asunder. I will screw in the pipe. As there is no pressure upon the bellows, the water stands in the pipe at the same level with that in the bellows at *z*.

Now place weights on the upper board till the water ascend exactly to the top of the pipe *e*: these weights express the weight of a pillar or column of water, the base of which is equal to the area of the lower board of the bellows, and the height equal to the distance of that board from the top of the pipe.

Emma. Will you make the experiment?

Father. Your brother shall first make the calculation.

Charles. But I must look to you for assistance.

Father. You will require very little of my help. Measure the diameter of the bellows, and the perpendicular height of the pipe from the bottom board.

Charles. The bellows are circular, and 12 inches in diameter; the height of the pipe is 36 inches.

Father. Well; you have to find the solid contents of a cylinder of these dimensions; that is, the area of the base multiplied by the height.

Charles. To find the area I multiply the square of 12 inches, that is, 144, by the decimals .7854, and the product is 113, the number of square inches in the area of the bottom board of the bellows. And 113 multiplied by 36 inches, the length of the pipe, gives 4068, the number of cubic inches in such a cylinder; this divided by 1728 (the number of cubic inches in a cubic foot,) leaves a quotient of 2.3 cubic feet, the solid contents of the cylinder. Still I have not the weight of the water.

Father. The weight of pure water is equal in all parts of the known world, and a cubical foot of it weighs 1000 ounces.

Charles. Then such a cylinder of water as we have been conversing about weighs 2300 ounces, or 144 pounds nearly.

Emma. Let us now see if the experiment answers to Charles's calculation.

Father. Put the weights on carefully, or you will dash the water out at the top of the pipe, and I dare say that you will find the fact agrees with the theory.

Charles. If instead of this pipe, one double the length was used, would the water sustain a double weight?

Father. It would: and a pipe three or four times the length would sustain three or four times greater weights.

Charles. Are there then no limits to this kind of experiment, except those which arise from the difficulty of acquiring length in the pipe?

Father. The bursting of the bellows would soon determine the limit of the experiment. Dr. Goldsmith says that he once saw a strong hogshead split by this means. A strong small tube made of tin, about 20 feet long, was cemented into the bung-hole, and then water was poured in to fill the cask: when it was full, and the water had

risen to within about a foot of the top of the tube, the vessel burst with prodigious force.

Emma. It is very difficult to conceive how this pressure acts with such power.

Father. The water at *o* is pressed with a force proportional to the perpendicular altitude *e o;* this pressure is communicated horizontally in the direction *o p q*, and the pressure so communicated acts, as you know, equally in all directions: the pressure, therefore, downwards upon the bottom of the bellows is just the same as it would be if *p q n r* were a cylinder of water.

The experiment made on the bellows might, for want of such an instrument, be made by means of a bladder in a box with a moveable lid.

Emma. Has this property of hydrostatics been applied to any practical purposes?

Father. The knowledge of it is of vast importance in the concerns of life. On this principle a press of immense power has been formed, (Plate II. Fig. 14.) which

we shall describe after you are acquainted with the nature and structure of valves, and which is used in many sea-port towns for pressing into small compass hay and other commodities which it is necessary to transport on board of ship, but which in their natural state would take up too much space.

CONVERSATION VI.

Of the Pressure of Fluids against the Sides of Vessels.

FATHER. Do you recollect, Charles, the law by which you calculated the accelerated velocity of falling bodies?*

Charles. Yes: the velocity increases in the same proportion as the odd numbers 1, 3, 5, 7, 9, &c.; that is, if at the end of one second of time it has carried the body through 16 feet; then in the next second the body will descend three times 16, or 48 feet: in the third it will descend five times

* Vol. I. Of Machanics. Conver. VII. and VIII.

16 feet, and in the next seven times 16 feet, and so on continually increasing in the same proportion.

Father. How many feet has it fallen altogether at the end of the *third* second?

Emma. I recollect this very well; the whole space through which it will fall in three seconds is nine times 16, or 144 feet; because the rule is, that the whole spaces described by falling bodies are in proportion to the squares of the times, and the square of three is nine, therefore if it fall through 16 feet in the first second, it will in three seconds fall through nine times 16, and in five or eight seconds it will descend in the former case through 25 times 16 feet, and in the latter through 64 times 16 feet, for 25 is the square of five, and 64 is the square of eight. The example of the arrow which you gave me to work has fixed the rule in my mind.

Father. Well, then, what I am going to tell you, will tend to impress the rule still stronger in your memory.

The pressure of fluids against the sides

any vessel increases in the same proportion, and is governed by the same laws.

Suppose *a b c d* (Plate II. Fig. 15.) to be a cubical vessel filled with water, or any other fluid, and one of the sides to be accurately divided into any number of equal parts by the lines 1, 7; 2, 8; 3, 9, &c.

Now if the pressure of the water upon the part of the vessel *a* 1 *b* 7 be equal to an ounce or a pound, then the pressure upon the part 1 2 7 8 will be equal to three ounces, or three pounds; and the pressure upon the part 2 3 8 9 will be equal to five ounces or pounds, and so on.

Charles. Then I see the reason why the other part of the rule holds true; viz. that the pressure against the whole side must vary as the square of the depth of the vessel.

Father. Explain to us the reason.

Charles. The pressure upon the *first* part being 1, and that upon the *second* 3, and that upon the *third* 5; then the pressure upon the first and second taken together is by addition 4: upon the first, second, and ...ust be 9; and upon the first, se-

cond, third, and fourth, it will be 16; but 4, 9, 16, are the squares of 2, 3, 4.

Emma. And the pressure upon the whole side *a b c d* must be 36 times greater than that upon the small part *a* 1 *b* 7.

Charles. And if there are three vessels, for instance, whose depths are as 1, 2, and 3, the pressure against the side of the second will be four times greater than that against the first; and the pressure against the side of the third will be nine time greater than that against the first.

Father. You are right: the beautiful simplicity of the rule, and its being the same by which the accelerating velocity of falling bodies is governed, will make it impossible that you should hereafter forget it.

The use that I shall hereafter call you to make of the rule, induces me to put a question to Emma.

In two canals, one five feet deep, and the other 15, what difference of pressure will there be against the sides of these canals?

Emma. The pressure against the one will be as the square of 5, or 25; that against

the other will be as the square of 15, or 225; now the latter number divided by the former gives 9 as a quotient, which shows that the pressure against the sides of the deep canal is 9 times greater than that against the sides of the shallow one.

Can this principal be proved by an experiment?

Father. By a very simple one: (Plate II. Fig. 16.) is a vessel of the same size as the last, the bottom and the side *b* are wood mortised together; the front and opposite side are glass carefully inserted in the wooden parts, and made water-tight. A thin board *c* hangs by two hinges *x y*, and is held close to the glass panes by means of the pulley and weight w. The board is covered with cloth and made water-tight.

Now observe the exact weight which is overcome when the water is poured in and rises to the line 1; then hang on four times that weight, and you will see that water may be poured into the vessel till it rise to the line 2, when the side *c* will give away and let part of it out.

Emma. But why does only a part run away?

Father. Because when a small quantity of the water has escaped, the weight w is greater than the pressure of the water against *c*, therefore the door *c* will be drawn close to the glass panes, and confine the rest within the vessels.

You may now hang on a weight nine times greater than the first, and then the vessel will contain water till it rise up to the mark 3, when the side will give way by the pressure, and part of the water escape.

Charles. You have explained the manner of estimating the pressure of fluids against the sides of a vessel; by what rule are we to find the pressure upon the bottom?

Father. In such vessels as those which we have just described: that is, where the sides are perpendicular to the bottom, and the bottom parallel to the horizon, *the pressure will be equal to the weight of the fluids.*

Emma. If then the vessel *y x* hold a gallon of water, which weights about eight

pounds, and if the bottom were made moveable like the side, would a weight of eight pounds keep the water in the vessel?

Father. It would: for the there would be an equilibrium between the pressure of the water and the weight. And the pressure upon any one side is equal to half the pressure upon the bottom; that is, provided the bottom and sides are equal to one another.

Charles. Pray, Sir, explain how this is made out.

Father. The pressure upon the bottom is, as we have shown, equal to the weight of the fluid. But we have also shown that the pressure on the side grows less and less continually, till at the surface it is nothing. Since then the pressure upon the bottom is truly represented by the area of the base multiplied into the altitude of the vessel; the pressure upon the side will be represented by the base multiplied into half the altitude.

Emma. Is the pressure upon the four sides equal to twice the pressure upon the bottom?

Father. It is: consequently the pressure of any fluid upon the bottom and four sides of a cubical vessel is equal to three times the weight of the fluid.

Can you, Charles, tell me the difference between the *weight* and the *pressure* of a conical vessel of water standing on its base?

Charles. The *weight* of a conical vessel of any fluid is found by multiplying the area the base by *one third part* of its perpendicular height*: but the *pressure* is found by multiplying the base by the whole perpendicular height; therefore the pressure upon the base will be equal to three times the weight.

Note.—The rule for finding the solidity of a cone or a pyramid is this, "Multiply the area of the base by $\frac{1}{3}$ of the height, and the product will be the solidity."

* See Bonnycastle's Introduction of Mensuration, &c. p. 132. Second Edition.

CONVERSATION VIII.

Of the Motion of Fluids.

FATHER. We will now consider the pressure of fluids with regard to the motion of them through spouting-pipes, which is subject to the same law.

If the pipes at 1 and 4 (Fig. 15.) be equal in size and length, the discharge of water by the pipe at 4 will be double that at 1. Because the velocity with which water spouts out at a hole in the side or bottom of a vessel, is as the *square-root* of the distance of the whole below the surface of the water.

Emma. What do you mean by the square-

Father. The square-root of any number is that which being multiplied into itself produces the said number. Thus the square-root of 1 is 1; but of 4 it is 2; of 9 it is 3; and of 16 it is 4, and so on.

Charles. Then if you had at all vessel of water with a cock inserted within a foot of the top, and you wished to draw the liquor off three times faster than it could be done with that; what would you do?

Father. I might take another cock of the same size, and insert it into the barrel at nine feet distance from the surface, and the thing required would be done.

Emma. Is this the reason why the water runs so slowly out of the cistern when it is nearly empty in comparison of what it does when the cistern is just full?

Father. It is: because the more water there is in the cistern, the greater the pressure upon the part where the cock is inserted; and the greater the pressure, the greater the velocity, and consequently the quantity of water that is drawn off in the same time.

In some large barrels there are two holes for cocks, the one about the middle of the cask, and the other at the bottom; now if when the vessel is full you draw the beer or wine from both cocks at once, you will find that the lower one gives out the liquor much faster.

Charles. In what proportion?

Father. As the square-root of 2 is greater than that of 1; that is, while you have a quart from the upper cock, three pints nearly would run from the lower one.

Emma. Are we then to understand that the *pressure* against the side of a vessel increases in proportion to the *square* of the depth; but the *velocity of a spouting pipe* which depends upon the pressure, increases only as the *square-root* of the depth?

Father. That is the proper distinction.

Charles. Is not the velocity of water, running out of a vessel that empties itself, continually decreasing?

Father. Certainly: because in proportion to the quantity drawn off, the surface de-

scends, and consequently the perpendicular depths becomes less and less.

The spaces described by the descending surface, in equal portions of time, are as the odd numbers 1, 3, 5, 7, 9, &c. taken backwards.

Emma. If the height of a vessel filled with any fluid be divided into 25 parts, and in a given space of time, as a minute, the surface descend through nine of those parts, will it in the next minute descend through seven of those parts, and the third minute five, in the fourth three, and in the fifth one?

Father. This is the law, and from it have been invented *clepsydras* or water-clocks.

Charles. How are they constructed Sir?

Father. Take a cylindrical vessel, and having ascertained the time it will require to empty itself, then divide, by lines, the surface into portions which are to one another as the odd numbers 1, 3, 5, 7, &c.

Emma. Suppose the vessel require six hours to empty itself, how must it be divided?

Father. It must first be divided into 36 equal parts; then, beginning from the surface, take 11 of those parts for the first hour, nine for the second, seven for the 3d, five for the 4th, three for the 5th, and one for the6th: and you will find that the surface of the water will descend regularly through each of these divisions in an hour.

I believe both of you have seen the locks that are constructed on the river Lea.

Charles. Yes: and I have wondered why the flood gates were made of such an enormous thickness.

Father. But after what you have heard respecting the pressure of fluids, you will see the necessity that there is for the great strength emyloyed.

Charles. I do: for sometimes the height of the water is 20 or 30 times greater on one side of the gates than it is on the other, therefore the pressure will be 400 or even 900 times greater against one side than it is against the other.

Emma. How are the gates opened when weight presses against them?

Father. There is scarcely any power by which they could be moved when this weight of water is against them; therefore there are sluices by the side, which being drawn up, the water gets away and passes into the bason till it becomes level on both sides; then the gates are opened with the greatest ease, because the pressure being equal on both sides, a small force applied will be sufficient to overcome the fraction of the hinges or other trifling obstacles.

Charles. It is this great pressure that sometimes beats down the banks of rivers?

Father. It is: for if the banks of a river or canal do not increase in strength in the proportion of the square of the depth, they cannot stand. Sometimes the water in a river will insinuate itself through the bank near the bottom, and if the weight of the bank be not equal to that of the water, it will assuredly be torn up, perhaps with great violence.

I will make the matter clear by a drawing. Suppose this figure (Plate II. Fig. 1

be a section of a river, and c a crevice or drain made by time under the bank *g*; by what we have shown before, the upward pressure of the water in that drain is equal to the downward pressure of the water in the river; therefore if that part of the bank be not as heavy as a column of water the same height and wedth, it must be torn up by the force of the pressure.

Charles. Is there no method of securing leaks that happen in the embankments of rivers?

Father. The only method is that called *puddling*. If *n* be the bank of a canal in which a leak is discovered, the water must be first drawn off below the leak, and a trench 18 or 20 inches wide dug lengthwise along the side of the canal, and deeper than the bottom of the canal: this is filled, by a little at a time, with clay or loam reduced into a half fluid state by mixing it with water: when the first layer, which is -bove six or eight inches deep, is , another is worked in the same

manner till the whole be filled. By this means, if the operation be performed by skilful hands, and time be allowed for all the parts to dry and cohere, the bank becomes strong and impenetrable.

CONVERSATION IX.

Of the Motion of Fluids.

FATHER. I will now show you an experiment by which you will observe the uniformity of nature's operations in regard to spouting fluids.

Charles. Do you refer to any other facts besides those which relate to the quantity of water issuing from pipes?

Father. Yes, I do. Let A B (Plate II. Fig. 18.) represent a tall vessel of water, which must be always kept full while the experiments are making. From the centre of this vessel I have drawn a semicircle, the diameter of which is the height of the ves-
I have drawn three lines, *d* 2

from the centre of the vessel; *c* 1, *a* 5, at equal distances from the centre, the one above and the other below it: all three are drawn perpendicular to the vessel. By taking out the plug from the centre you will see the water spouts to M. Take your compasses and you will find that the distance N M is exactly double the length of *d* 2. I will now stop this plug and open the next below.

Charles. The water reaches to K, which is double the length of *a* 5.

Father. Try in the same manner the pipe *c*.

Charles. It falls at the same spot K as it did from the lower one.

Father. Because the lines *c* 1 and *a* 5 being equally distant from the centre of the semicircle, they are equal to one another.

Emma. Then N K is the double of *c* 1, as well as of *a* 5.

Father. It is. The general rule deduced from these experiments is, that the horizontal distance to which a fluid will spout from an horizontal pipe, in any part of

the side of an upright vessel below the surface of the fluid, is equal to twice the length of a perpendicular to the side of the vessel, drawn from the mouth of the pipe to a semicircle described upon the altitude of the vessel.

Can you, Charles, tell me in what part the pipe should be placed, in order that the fluid should spout the farthest possible?

Charles. In the centre: for the line *d* 2 seems to be the greatest of all the lines that can be drawn from the vessel to the curved line.

Father. Yes, it is demonstrable by geometry that this is the case; and that lines at equal distances from the centre above and below are also equal to each other.

Emma. Then in all cases, if pipes are placed equally distant from the centre, they will spout to the same point.

Father. They will. Instead of horizontal pipes, I will fix three others near N, which shall point obliquely upwards at different angles; one at 22° 30′, the second [illegible] the third at 67° 30′, and you

will see that when I open the cocks, the water will cut the curve line nearly, but not accurately, in those parts to which the horizontal lines were drawn.

Charles. That which spouts from the centre, is thrown to the point *x*, as it was from the centre horizontal pipe. The two others fall on the point K, on which the upper and lower horizontal pipes ejected the stream.

Emma. I thought the water from the upper cock did not reach so high as the mark.

Father. It did not. The reason is, that it had to pass through a larger body of air, and the resistance from that retarded the water and prevented it from ascending to the point to which it would have ascended if the air had been taken away.

While we are on this subject, I will just mention, that as you see the water spouts the farthest when the pipe is elevated to an angle of 45°, so a gun, cannon, &c. will project a bullet the farthest if it be elevated to an angle of 45°.

Charles. Will a cannon or mortar carry a ball equally distant if it be elevated at angles equally distant from 45°, the one above and the other below?

Father. It will in theory: but owing to the great resistance which very swift motions meet with from the air, there must be allowances made for some considerable variation between theory and practice.

A regard to this will explain the reason why water will not rise so high in a jet as it does in a tube.

Emma. I do not know what this means.

Father. You have seen a fountain.

Emma. Yes, I have often been amused with that in the Temple.

Father. All fountains are called jets, or *jets d'eau.* Now if the water of that in the Temple ascended in a pipe, it would rise higher than it does in the open air. Turn to Fig. 10, the water in the small tube rises to a level with that in the larger one; now if the tube H G were broken off at *t*, the water would spout up like a fountain, but ... high as it stands in the tube, per... higher than to *d*.

Charles. Is that owing wholly to the resistance of the air?

Father. It is to be ascribed to the resistance which the water meets with from the air and to the force of gravity, which has a tendency to retard the motion of the steam.

Emma. Why does the fountain in the Temple sometimes play higher and sometimes lower?

Father. Near the Temple-hall there is a reservoir of water, from which a pipe communicates with the jet in the fountain: and according as the water in the reservoir is higher or lower, the height to which the fountain plays is regulated.

Charles. By turning a cock near the pump, the fountain is instantly lowered.

Father. That cock is likewise connected with the reservoir, and therefore taking water from it must have the effect of lowering the stream at the fountain, as well as that in the reservoir.

Emma. It soon recovers its force again.

Father. Because there is a constant ply of water to the reservoir, which,

ever, does not come in so quick as the cock lets it out, or the fountain would always play to the same height.

From what you have already learnt on this subject, you will be able to know how London and other places are supplied with water.

Charles. London is, I believe, supplied from the New River, but I do not know in what manner.

Father. The New River is a stream of water that comes from Ware in Hertfordshire; it runs into a reservoir situated on the high ground near Islington. From this reservoir pipes are laid into those parts of town that have their water from the New River, and through these pipes the water flows into cisterns belonging to different houses.

Emma. Then the reservoir at Islington must be higher than the cisterns in London.

Father. Certainly, because water will not rise above its level. On this account some ...igher parts of town have hitherto

been supplied from the ponds at Hampstead; and others are supplied from the Thames, by means of the water works at London-bridge.

Charles. Are pipes laid all the way from Hampstead to town?

Father. They are; but these supply the intermediate villages, as well as London: and Hampstead standing so high, the water is carried up into the first and second stories in some houses. Thus you see that water may be carried to any distance, and houses on different sides of a deep valley may be supplied by water from the same spring-head. You must remember that if the valleys are very deep, the pipes must be exceedingly strong near the bottom, because the pressure increases in the rapid proportion of the odd numbers 1, 3, 5, 7, &c. and therefore, unless the strength of the wood or iron be increased in the same proportion the pipes will be continually bursting.

Emma. You told me the other day, that the large mound of earth, for it appears nothing else, near the end of Tottenham-

court-road, was intended as a reservoir for the New River.

Father. What appears to you, and others who pass by it, only as a mound of earth, is an exceedingly large bason capable of containing a great many thousand hogsheads of water.

Charles. How will they get the water into it?

Father. At Islington, near the New River Head, is made a large reservoir upon some very high ground, into which, by means of a steam-engine, they will constantly throw water from the New River. This reservoir being higher than that in Tottenham-court-road, nothing more is necessary than to lay pipes from Islington to that place in order to keep it constantly full of water.

By this contrivance the New River company will be able to extend their business to other parts of London where their present head of water cannot reach.

Charles. The weight of water in this must be immensely great.

Father. It must; and therefore you observe what a thickness the mound of earth against the wall is towards the bottom, and that it diminishes towards the top as the pressure becomes less and less.

Emma. Would not the consequences be very serious if the water were to insinuate itself through the earth at the bottom?

Father. If such an accident were to happen when the reservoir was full of water, it would probably tear up the works and do incredible mischief. To prevent this, the vast bank of earth is sloped within, as well as without; it will then be covered with a strong coating of clay; after this it will be built up with a very thick brick-wall, which will be carefully tarrassed over; so that the whole mass will be as firm and compact as a glass bottle.

CONVERSATION X.

Of the Specific Gravities of Bodies.

EMMA. What is the reason, Papa, that some bodies as lead or iron, if thrown into the water, sink while others, as wood, will swim?

Father. Those bodies that are heavier than water will sink in it, but those that are lighter will swim.

Emma. I do not quite comprehend your meaning; a pound of wood, another of water, and another of lead, are all equally heavy. For Charles played me a trick the other day: he suddenly asked which was

heavier, a pound of lead or a pound of feathers? I said the lead, and you all laughed at me, by which I was soon led to perceive, that a pound, or 16 ounces of any substance whatever, must be always equal to the same weight.

Father. You are not the first person that has been taken in by this question. It is a common trick. Although a pound of lead and another of water be equally heavy, yet they are not of equal magnitudes. Do you know how much water goes to a pound?

Charles. Yes; about a pint.

Father. Do you think that if I were to fill the same pint measure with lead, that would weigh a pound only?

Charles. Oh no; that would weigh a great deal more. I do not believe that the 14 pound weight below stairs is much larger than a pint measure.

Father. Yes it is, by about a fourth part: the same measure that contains one pound of water, would, however, contain about 11 pound of lead: but it would contain 14 pounds of quicksilver, which, you know

could as easily pour into the vessel as if it were water.

Here are two cups of equal size; fill the one with water, and I will fill the other with quicksilver.

Emma. Why did you not let Charles pour out the quicksilver?

Father. The loss of water is a matter of little consequence; but if, by chance, he had thrown down the quicksilver, the accident might have occasioned the loss of sixpence, or a shilling; and economy is right in all the affairs of life. Take the cups in your hand: which is the heavier?

Charles. The quicksilver by much.

Father. But the two cups are of equal size.

Emma. Then there must be equal quantities of water and quicksilver.

Father. They are equal in bulk.

Charles. But very unequal in weight: shall I try how much heavier the one is than the other.

Father. If you please. In what manner ascertain the matter?

Charles. I will carfully weigh the two cups, and then dividing the large weight by the smaller, I shall see how many times heavier the quicksilver is than the water.

Father. You will not come to the point accurately by that means; because the weight of the cups is probably equal, but by this method they ought to differ in weight in the same proportion as the two substances.

Emma. Then pour the quicksilver first into the scale and weigh it; afterwards do the same with the water; and divide the former by the latter: will not that give the result?

Father. Yes, it will: or you may make the experiment in this method.

Here is a small phial, that weighs, now it is empty, an ounce; fill it with pure rain water, and the weight of the whole is two ounces.

Charles. Then it contains one ounce of water.

Father. Pour out the water and let it be well dried both within and without; fill it now

very accurately with quicksilver, and weigh it again.

Emma. It weighs a little more than 15 ounces: but as the bottle weighs one ounce, the quicksilver weighs something more than 14 ounces.

Father. What do you infer from this, Charles?

Charles. That the quicksilver is more than 14 times heavier than water.

Father. I will now pour away the quicksilver, and fill the phial with pure spirits of wine, or, as the chemists call it, with *alcohol.*

Emma. It does not weigh two ounces now, consequently the fluid does not weigh an ounce. The alcohol is, then, lighter than water.

Father. By these means, which you cannot fail of understanding, we have obtained the *comparative weights* of three fluids; philosophers, as I have before told you, call these comparative weights, the *specific gravities* of the fluids: they have agreed also to make pure rain water the standard to which

they refer the comparative weights of all other bodies, whether soild or fluid.

Charles. Is there any particular reason why they refer water to every other substances?

Father. I told you a few days ago, that rain water, if very pure, is of the same weight in all parts of the world: and, what is very remarkable, a cubical foot of water weights exactly a thousand ounces avoirdupoise: on these accounts it is admirably adapted for a standard, because you can at once tell the weight of a cubical foot of any other substance, if you know its specific gravity.

Emma. Then a cubical foot of quicksilver weighs 14,000 ounces.

Father. You are right; and if lead is 11 times heavier than water, a cubical foot of it will weigh 11,000 ounces.

CONVERSATION XI.

Of the Specific Gravities of Bodies.

FATHER. Before we enter upon the methods of obtaining the specific gravities of different bodies, it will be right to premise a few particulars, which it is necessary should be well understood.

You now understand, that the specific gravity of different bodies depends upon the different quantities of matter which equal bulks of these bodies contain.

Charles. As the *momenta** of different

* See Vol. I. Of Mechanics. Conver. VI.

bodies are estimated by the quantities of matter when the velocities are the same; so the specific gravity of bodies is estimated by the quantities of matter when the bulks or magnitudes are the same. This, I believe, is what you mean.

Father. I do: if you had a piece of wood, and another piece of lead, both exactly equal in size to a copper penny-piece, the former would be much lighter, and the latter considerably heavier, than the copper.

Charles. And I should say that the specific gravity of the wood is less than that of the copper, but of the lead it is greater.

Emma. Is it then the *density* that constitutes the specific gravity?

Father. Undoubtedly it is: and, as we observed yesterday, water is made use of as a medium to discover the different specific gravities of different bodies; and also as a standard to which they may be all referred.

Here are three pieces of different kinds of wood, which I will put into this vessel of water: one sinks to the bottom; a second remains in any position of the water in

which it is placed; and the third swims on the water with more than half of the substance above its surface.

Charles. The first, then, is heavier than the water, the second is of the same weight with an equal bulk of the fluid, and the third is lighter.

Father. Since fluids press in all directions, a solid that is immersed in water sustains a pressure on all sides, which is increased in proportion to the height of the fluid above the solid.

Emma. That seems natural, but an experiment would fix it better in the mind.

Father. Tie a leathern bag (Plate I. Fig. 8.) to the end of a glass tube, and pour in some quicksilver. Dip the bag in water, and the upward pressure of the fluid will raise the quicksilver in the tube, the ascent of which will be higher or lower, in proportion to the height of the water, above the bag.

Emma. I now understand that the upper part of the tube being empty, or, at least, only filled with air, the upward pressure of

the water against the bag must be greater than the downward pressure of the air: and that as the pressure increases according to the depth, therefore the murcury must keep rising in the tube.

What is the reason that a body heavier than water, as a stone, sinks to the bottom, if the pressure upward is always equal to that downwards?

Father. This is a very proper question. The stone endeavours to descend by the force of gravity: but it cannot descend without moving away as much of the water as is equal to the bulk of the stone; therefore it is resisted, or pressed upwards, by a force equal to the weight of as much water as is equal in magnitude to the bulk of the stone; but the weight of the water is less than that of the stone, consequently the force pressing against it upwards in *less* than its tendency downwards, and therefore it will sink with the *difference* of those two forces.

You will now be at no loss to understand the reason why bodies lighter than water swim:

As passing straws and buoyant leaves
The yielding surface but receives;
While pearls, that lure the searching eye,
Deep treasur'd in its bosom lie.
May trifles such reception find,
Float merely transient on my mind,
While weightier thoughts admission win,
Sink its whole depths, and rest within.

BROWNE.

Charles. The water being heavier, the force upwards is greater than the natural gravity of the body, and it will be buoyed up by the difference of the forces.

Father. Bodies of this kind, then, will sink in water, till so much of them is below the surface, that a bulk of water equal to the bulk of the part of the body which is below the surface, is of a weight equal to the weight of the whole body.

Emma. Will you explain this more particularly?

Father. Suppose the body to be a piece of wood, part of which will be above and part below the surface of the water: in this state conceive the wood to be frozen into

water.

Charles. I understand you: if the wood be taken out of the ice, a vacuity will be left, and the quantity of water that is required to fill that vacuity will weigh as much as the whole substance of the wood.

Father. That was what I meant to have said.

There is one case remaining:—where equal bulks of the water and the wood are of the same weight, the force with which the wood endeavours to decend, and the force that opposes it, being equal to one another, and acting in contrary directions, the body will rest between them, so as neither to sink by its own weight, nor to ascend by the upward pressure of the water.

Emma. What is the meaning of this glass jar with the images in it? (Plate III. Fig. 19.)

Father. I placed it on the table in order to illustrate our subject to-day. You observe that, by pressing the bladder with my hand, the three images all sink.

Emma. But not at the same moment.

Father. The images are made of glass

and about the same specific gravity with the water surrounding them, or perhaps rather less than it, and consequently they all float near the surface. They are hollow, with little holes in the feet. When the air, which lies between the bladder and the surface of the water, is pressed by my hand, there is a pressure on the water which is communicated through it, and that part of it which lies contiguous to the feet of the images will be forced into their bodies, by which their weight is so much increased as to render them heavier than the water, and they descend.

Charles. Why do they not all descend to the same depths?

Father. Because the hollow part of the image E is larger than the hollow part of D, and that is larger than that of C; consequently the same pressure will force more water into E than into D, and more into D than into C.

Emma. Why do they begin to ascend now you have taken your hand away?

Father. I said the hollow parts of the

images were empty, which was not quite correct: they were full of air, which, as it could not escape, was compressed into a smaller space when the water was forced in by the pressure upon the bladder. But as soon as the pressure is removed, the air in the images expands, drives out the water, and they become as light as at first, and will therefore rise to the surface.

Charles. The images in rising up to the surface turned round.

Father. This circular motion is owing to the hole being on one side; and when the pressure is taken off, the water issuing out quickly is resisted by the water in the vessel, and the reaction being exerted on one foot, turns the figure round.

CONVERSATION XII.

Of the Methods of finding the Specific Gravity of Bodies.

EMMA. What are you going to weigh with these scales?

Father. This instrument (Plate III. Fig. 20.) is called the hydrostatical balance; it differs but little from the balance in common use. Some instruments of this kind are more complicated, but the most simple are best adapted to my purpose.

To the beam two scale-pans are adjusted, and may be taken off at pleasure. There is also another pan A, of equal weight with one of the others, furnished with shorter strings and a small hook, so that any body

may be hung to it, and then immersed in the vessel of water B.

Charles. It is by means of this instrument that you find the specific gravity of different bodies?

Father. It is: I will first give you the rule, and then illustrate it by experiments. The rule should be committed to memory.

"Weigh the body first in air; that is, in the common method: then weigh it in water; observe how much weight it loses by being weighed in water, and by dividing the former weight by the loss sustained, the result is its specific gravity, compared with that of the water."

I will give you an example.—Here is a new guinea: it weighs in the air 129 grains: I suspend it by a fine thread of horse-hair to the hook at the bottom of the pan A, and you that by being immersed in water it weighs only $121\frac{3}{4}$ grains.

Emma. Then in the water it has lost of its weight $7\frac{1}{4}$ grains.

Father. Divide 129 by $7\frac{1}{4}$, or, by turning the $\frac{1}{4}$ into decimals, by 7.25.

before, it drives over a quantity of the fluid equal in weight to itself. Put in two penny-pieces, and you perceive the box sinks deeper into the water.

Charles. And they drive more water over: as much, I suppose, as is equal in weight to the copper coin.

Father. Right: how long could you go on loading the box?

Charles. Till the weight of the copper and box, taken together, is something greater than the weight of as much water as is equal in bulk to the box.

Father. You understand, then, the reason why boats, barges, and other vessels, swim on water; and to what extent you may load them with safety.

Emma. They will swim so long as the weight of the vessel and its lading together, is less than that of a quantity of water, equal in bulk to the vessel.

Father. Can you, Charles, devise any method to make iron or lead swim, which are so much heavier than water?

Charles. I think I can. If the metal be beat out very thin, and the edges turned up, I can easily conceive that a box or a boat of it may be made to swim. Of this kind is the copper ball which is contrived to turn off the water when the cistern is full.

Emma. I have often wondered how that acts.

Father. If upon reflection you could not satisfy yourself about the mode of its acting, you should have asked; it is better to get information from another than to remain ignorant.

The ball, though made of copper, which is eight or nine times heavier than water, is beat out so thin, that its bulk is much lighter than an equal bulk of water. By means of a handle it is fastened to the cock, through which the water flows, and as it sinks or rises, it opens or shuts the cock.

If the cistern is empty, the ball hangs down, and the cock is open, to admit the water freely: as the water rises in the cistern it reaches the ball, which, being lighter than the water, rises with it, and, by rising,

gradually shuts the cock, and, if it be properly placed, it is contrived to shut the cock just at the moment that the cistern is full.

In the same way that these balls are made, boats of iron are now constructed at the iron-works in Shropshire: they will last longer than wood, and cause less friction in passing through the water.

Can you, Emma, find the specific gravity of this piece of silver?

Emma. It weighs in air 318 grains: I now fasten it to the hook with the horse-hair, and it weighs in water 288 grains, which, taken from 318, leave 30, the weight it lost in water. By dividing 318 by 30, the quotient is about $10\frac{1}{2}$, consequently the specific gravity of the silver is ten and a half times greater than that of water.

Father. What is the specific gravity of this piece of flint-glass? It weighs 12 pennyweights in air.

Charles. And in water it weighs only 8, and consequently loses 4 by immersion; and 12 divided by 4 gives 3, therefore the

specific gravity of flint-glass is 3 times greater than that of water.

Father. This is not the case with all flint-glass; it varies from 2 to almost 4.

Here is an ounce of quicksilver; let me know its specific gravity by the method now proposed.

Emma. How will you manage that? you cannot hang it upon the balance.

Father. But you may suspend this glass bucket (Plate III. Fig. 21.) on the hook at the bottom of A; immerse it in the water, and then balance it exactly with weights in the opposite scale.

I will now put into the bucket the ounce, or 480 grains of quicksilver, and see how much it loses in water.

Charles. It weighs 445 grains, and consequently it lost 35 grains by immersion; and 480 divided by 35 give almost 14, so that mercury is almost 14 times heavier than water.

Father. In the same manner we obtain the specific gravity of all bodies that consist of small fragments. They must be put in-

to the glass bucket and weighed; and then if from the weight of the bucket and body in the fluid, you subtract the weight of the bucket, there remains the weight of the body in the fluid.

Emma. Why do you make use of horse-hair to suspend the substances with? would not silk or thread do as well?

Father. Horse-hair is by much the best, for it is very nearly of the same specific gravity of water; and its substance is of such a nature as not to imbibe moisture.

CONVERSATION XIII.

Of the Methods of finding the Specific Gravity of Bodies.

CHARLES. I have endeavoured to find out the specific gravity of this piece of beech-wood; but, as it will not sink in the water, I know not how to do it.

Father. It is true, that we have hitherto only given rules for the finding of the specific gravity of bodies that are heavier than water; a little consideration, however, will show you how to obtain the specific gravity of the beech. Can you contrive means to sink the beech in the water?

Charles. Yes; if I join a piece of lead, or other metal, to the wood, it will sink.

Father. The beech weighs 660 grains; I will annex to it an ounce, or 480 grains of tin, which in water loses of its weight 51 grains. In air the weight of the wood and metal taken together is 1140 grains: but in water they weigh but 138 grains; 138 taken from 1140 leave 1002, the difference between the weights in air and in water.

Charles. I now see the mode of finding what I want. The whole mass loses 1002 grains by immersion, and the tin by itself lost in water 51 grains; therefore the wood lost 951 grains of its weight by immersion: and 660 grains, the weight of the beech in air, divided by 951, which it may be said to lose by immersion, leaves in decimals for a quotient 694.

Father. Then making water the standard equal to 1, the beech is 694, or nearly $\frac{7}{10}$ths of 1: that is, a cubic foot of water is to a cubic foot of beech as 1000 to 694,

for the one weighs 1000 ounces, and the other 694 ounces.

Emma. It seems odd how a piece of wood that weighs about 660 grains in air, should lose of its weight 951 grains.

Father. You must, in this case, consider the weight necessary to make it sink in water, which must be added to the weight of the wood.

I will now endeavour to make the subject easier by a different method.

This small piece of elm *a*, I will place between the tongs (Plate III. Fig. 22.) that are nicely balanced on the beam, (Fig. 20.) The elm weighs 36 grains. To detain it under water, I must hang 24 grains to the end of the lever on which the tongs are fixed: then, by the Rule of Three, I say, as the specific gravity of the elm is to the specific gravity of water, so is 36, the weight of the elm, to 60, the weight of the elm and the additional weight required to sink it in water, or as 60 : 36 :: S. G. W. S. G. E.

Emma. You have not obtained the specific gravity of the elm, but a proportion only.

Charles. But three terms are given, because the water is always considered as unity or 1, therefore the specific gravity of the elm is

$$\frac{36\times 1}{60}=.6.$$

Emma. I do not yet comprehend the reason of the proportion assumed.

Father. It is very simple. The elm is lighter than the water, but by hanging weights to the side of the balance, to which it is attached in order to detain it just under water, I make the whole exactly equal to the specific gravity of the water; by this means it is evident, that the comparative gravity of the elm is to that of the water as 36 to 60.

Try this piece of cork in the same manner.

Emma. It weighs $\frac{1}{2}$ an ounce, or 240 and to detain the cork and

tongs just under water, I am obliged to hang 2 ounces, or 960 grains, of lead on the lever: therefore the specific gravity of the cork is to that of the water as 240 is to 1200; and 240 divided by 1200 gives the decimal .2.

Father. Then the specific gravity of water is 5 times greater than that of cork.

Charles. We have accordingly obtained the specific gravities of water, beech, elm, and cork, which are as 1, .7 nearly .6 and .2.

Father. You now understand the methods of obtaining the specific gravity of all solids, whether lighter or heavier than water. In making experiments upon light and porous woods, the operations must be performed as quickly as possible, to prevent the water from getting into the pores.

Charles. And you have likewise shown us a method of getting the specific gravity of fluids, by weighing certain quantities of each.

Father. I have still a better method:

the rule I will give in words: you shall illustrate it by examples.

"If the same body be weighed in different fluids, the specific gravity of the fluids will be as the weights lost."

Emma. The body made use of must be heavier than the fluids.

Father. Certainly; this glass ball loses of its weight, by immersion in water, 803 grains; in milk it loses 831 grains; therefore the specific gravity of the water is to that of milk as 803 to 831. Now a cubical foot of water weighs 1000 ounces: what will be the weight of the same quantity of milk?

Emma. As 803 : 831 : : 1000 : $\frac{1000 \times 831}{803}$ = 1035 ounces nearly.

Father. Do you, Charles, tell me what is the specific gravity of some spirits of wine which I have in this phial.

Charles. The glass loses in water 803 grains, in the spirit of wine it loses 699 ... -fore the specific gravity of wa-

ter is to the spirit as 803 is to 699: and to find the weight of a cubical foot of the spirit, I say, as

$$803 : 699 :: 1000 : \frac{1000 \times 699}{803} =$$

870 ounces.

Father. You may now deduce the method of comparing the specific gravities of solids one with another without making a common standard.

Here is an ounce of lead and another of tin: I may weigh them in any fluid whatever: in water the lead loses by immersion 42 grains, and the tin 63 grains.

Emma. Is the specific gravity of the lead to that of the tin as 42 to 63?

Father. No: "the specific gravities of "bodies are to one another *inversely* as the "losses of weight sustained:" therefore the specific gravity of the lead is to that of the tin as 63 to 42; or if a block of lead weighs 63 pounds, the same sized block of tin will weigh 42 pounds only.

Charles. I think I see the reason of this: the heavier the body, the less it loses of its weight by immersion; therefore, of two bodies whose absolute weights are the same, that is, each weighing an ounce, pound, &c. the one which loses least of its weight will be the most specifically heavy.

Father. You are right; for the specific gravity of bodies is as their density, and their densities are inversely as the weights they lose by immersion; that is, the body that is most dense will lose the least in water.

CONVERSATION XIV.

Of the Methods of obtaining the Specific Gravity of Bodies.

FATHER. As I have shown you the methods of finding the specific gravity of almost all kinds of bodies, it will be proper in this, and one or two lessons, to show you the practical utility of this part of science.

Emma. To whom are we indebted for the discovery of the mode of performing these operations?

Father. To that most celebrated mathematician of antiquity, Archimedes.

Charles. Was he not slain by a common soldier at the siege of Syracuse?

Father. He was, to the great grief of Marcellus, the Roman commander, who had ordered that his house and person should be respected: but the philosopher was too deeply engaged in solving some geometrical inquiries to think of seeking that protection which even the enemy intended for him.

Emma. Had he at that time so high a reputation as to induce the general of a besieging army to give particular orders for his preservation?

Father. His celebrity was so great among the literati of Rome, that his tragical end caused more real sorrow than the capture of the whole island of Sicily did joy.

We are informed by history, that it was by the wisdom of Archimedes that the fate of Syracuse was long suspended: by his inventions multitudes of the Roman army were killed, and their ships destroyed: and it is added that he made use of burning which, at the distance of some

hundreds of yards, set the Roman vessels on fire.

Charles. I wonder then that he was not defended by his fellow citizens.

Father. Alas! my child, I am sorry to say, that in other countries, as well as Sicily, there have been instances in which persons, who have benefited their country as much as Archimedes, have experienced no more gratitude than he did.

It is a fortunate circumstance when the efforts of philosophy are directed, under able judgment, to the defence of one's country. The Romans had no more right to plunder Sicily than the highwayman has to rifle your pockets or mine. In the eye of reason and justice, *offensive* war is the most deliberate and cruel system of robbery and murder.

But to return to our subject. To Archimedes the world is indebted for the discovery, "That every body heavier than its "bulk of water, loses so much of its "weight, by being suspended in water, as

s equal to the weight of a quantity of rater equal to its bulk."

Emma. How did he make the disco-y?

Father. Hiero, king of Syracuse, had en to a jeweller a certain quantity of e gold, to make a crown for him. The narch, when he saw the crown, suspected artist of having kept back part of the d.

Emma. Why did he not weigh it?

Father. He did; and found the weight it: but he suspected, perhaps from the our of the crown, that some baser metal been mixed with the gold, and there- though he had his weight, yet only a t of it was gold, the rest was silver or per. He applied to Archimedes to in-tigate the fraud.

Charles. Did he melt the crown, and eavour to separate the metals?

Father. That would not have answered ro's intentions: his object was to de- ory, if any, without destroying

the workmanship. While the philosopher was intent upon the problem, he went, according to his custom, into the bath, and he observed that a quantity of water flowed over, which he thought must be equal to the bulk of his own body. He instantly saw the solution of Hiero's problem. In raptures at the discovery, he is said to have leaped from the water, and run naked through the streets of the city, shouting aloud Ευρηκα! Ευρηκα! "I have found it out! I have found it out!"

When the excess of his joy was abated, he got two masses, one of gold, and the other of silver, each equal in weight to the crown, and having filled a vessel very accurately with water, into which he first dipped the silver mass and observed the quantity of water that flowed over: he then did the same with the gold, and found that a less quantity of water had flowed over than before.

Charles. And was he, from these trials, led to conclude that the bulk of the silver was greater than that of the gold?

Father. He was. And also that the bulk of water displaced was, in each experiment, equal to the bulk of the metal. He then made the same trial with the crown, and found, that though of the same weight with the masses of silver and gold, yet it displaced more water than the gold, and less than the silver.

Emma. Accordingly he concluded, I imagine, that it was neither pure gold, nor pure silver.

Charles. But how could he discover the proportions of each metal?

Father. I believe we have no other facts to carry us farther into the history of this interesting experiment. But to-morrow I will endeavour to explain and illustrate the matter.

CONVERSATION XV.

Of the Methods of obtaining the Specific Gravity of Bodies.

EMMA. You are to describe, to-day, the method of detecting the proportion of each metal if two are mixed together in one mass.

Father. Suppose I take in change a guinea, which I suspect to be bad: upon trying it I find it weighs 129 grains, which is the standard weight of a guinea. I then weigh it in water, and it loses of its weight 8¼ grains, by which I divide the 129, and the quotient is 15.6, the specific gravity of the guinea. But you know the specific gravity of the gold, in Tower-made guineas, is

more than 17, and therefore I conclude the guinea is base metal, a mixture of silver, or copper, with standard gold.

Charles. But how will you get the proportions of the two metals?

Father. Suppose, for example, that the mass be a compound of silver and gold.—"Compute what the loss of a mass of standard gold would be; and likewise the loss "which a mass of silver equal in weight to "the guinea would sustain. Subtract the "loss of the gold from that of the compound, "the remainder is the ratio or proportion "(not the quantity) of the silver: then subtract the loss of the compound from that "of the silver, the remainder is the proportion of the gold." I will propose you an example.

What are the proportions of silver and gold in a guinea weighing 129 grains, whose specific gravity is found to be only 13.09; supposing the loss of standard gold 7.25, and that of a piece of silver, equal in weight to a guinea, 12.45, and the loss of the com-...d 9.85?

Charles. I first subtract the loss of standard gold 7.25 from the loss of the compound 9.85, the remainder is 2.6: I now take the loss of the compound 9.85, from that sustained by the silver 12.45, and the remainder is also 2.6.

Father. Then the proportions of silver and gold are equal to one another, consequently the false guinea is half standard gold and half silver.

Here is another counterfeit guinea, which is full weight, but I know it is composed of standard gold, adulterated with copper, and its loss in water is, as you see, 8.64: now tell me the proportions of the two metals; but you should be informed that a piece of copper of the weight of a guinea would lose in water 14.65 grains.

Emma. I deduct 7.25, the loss of a guinea standard gold, from 8.64, the remainder is 1.39: I now take the loss of the compound 8.64 from 14.65, the loss sustained by a piece of copper equal in weight to a guinea, and the remainder is 6.01. Is not the proportion of copper to gold as 1.39 to 6.01?

Father. You are quite right. Now, by the rule of three, tell me the quantity of each metal.

Emma. To find the weight of the copper, I add 6.01, and 1.39 together, which are the *proportional* weights of the two metals. And say, as 7.40, the sum, is to 1.39 the *proportional weight* of copper, so is the weight of the guinea, 129 grains, to the *real weight* of copper contained in the counterfeit guinea: but

$$\frac{1.39 \times 129}{7.40} = 24.1,$$ therefore there is a little more than 24 grains of copper in the compound.

Father. You have found then that there are 24 grains of copper in this counterfeit guinea. How will you find the weight of the gold?

Emma. Very easily: for if the composition be copper and gold, and there are found to be 24 grains of copper, there must be 105 of gold.

Charles. I have a question to propose. ...hance you take a bad guinea (I have

heard you say that you never attempt to pass bad money upon others), how should you be able to ascertain the value it would fetch at the goldsmith's?

Father. It is certainly very wrong knowingly to pass bad money upon the public: no man has a right to commit an injury because he has received one; if, therefore, I have taken counterfeit money, I ought to abide by the loss, rather than run the risk of injuring my neighbour: besides, in the course of circulation, a bad guinea, or a seven-shilling piece, or even coins of much less value, may fall into the hands of a poor and industrious family, which they perhaps laid by to answer the extraordinary demands of sickness; and at that period of distress, not being able to say from whom they received the counterfeit coin, they may possibly be reduced to serious and pitiable difficulties: and therefore it is better for me to put up with the loss than run the hazard of injuring the poor.

Now to answer your question. A piece of copper, of equal weight with a guinea,

loses of its weight in water 14.65 grains, 7.4 more than is lost by a standard guinea. The value of a standard guinea is 252 pence, divide therefore 252 by 7.4 and you get 34, the number of pence that is deducted, from the value of a guinea, for every grain it loses more than it would lose if it were sterling gold.

Emma. In the guinea that lost 8.64 how much must be deducted from the real value of a guinea standard gold?

Charles. I can tell that; subtract 7.25 from 8.64 the remainder is 1.39, and this multiplied by 34 pence gives 47.26 pence, or very nearly 4 shillings, consequently that guinea is worth only 17 shillings.

Father. Suppose the compound were silver and gold, how would you proceed in making an estimate of its value?

Charles. A piece of silver of the weight of a guinea would lose 12.45 grains, from which I deduct 7.25, and with the remainder 5.2 I divide the value of a guinea, or 252 pence, and the quotient is 48.4 pence,

or rather more than 4 shillings is to be deducted from the value of a guinea adulterated with silver, for every grain it loses by immersion more than standard gold.

Emma. How is that, Papa? Silver is much dearer than copper, and yet you allow 4 shillings a grain when the guinea is alloyed with silver, and but 2s. 10d. when the mixture is made with copper?

Father. Because the specific gravity of silver is much nearer to that of gold, than that of copper, consequently if equal quantities of silver and copper were mixed with gold, the silver would cause a much less loss by immersion in water than the copper.

As it seldom happens that the adulteration of metal in guineas is made with all copper, or with all silver, but generally with a mixture of both, three shillings is upon the average allowed for every grain that the base metal loses by immersion in water more than sterling gold.

Emma. There is a silver cream jug in the

parlour; I have heard Mamma say, she did not think it was real silver; how could she find out whether she has been imposed on?

Father. Go and fetch it. We will no weigh it.

Emma. It weighs $5\frac{1}{2}$ ounces, but I mu weigh it in water, and it has lost in the wa ter, $10\frac{1}{4}$ dwts; and dividing $5\frac{1}{2}$ ounces, 110 penny-weights by $10\frac{1}{4}$, I get for answ 10.7, the specific gravity of the jug.

Father. Then there is no cause for co plaint, for the specific gravity of goo wrought silver is seldom more than this

Table of Specific Gravities.

Distilled water	1.
Sea water	1.
Standard gold	17.
Mercury	13.
Standard silver	10.
Lead	11.
[illegible]	8

Copper	7.788
Tin	7.291
Iron (cast)	7.207
Iron (bar)	7.788
Zinc	7.191
Flint-Glass	3.290
Ivory	1.825
Oil	.940
Cork	.240

Platina

[illegible]

CONVERSATION XVI.

Of the Hydrometer.

FATHER. Before I describe the construction and uses of the hydrometer, I will show you an experiment or two which will afford you entertainment, after the dry calculations in some of our former conversations.

Charles. The arithmetical operations are rather tedious to be sure, but they serve to bring to mind what we have already learnt, and at the same time show to what uses arithmetic may be applied.

Father. You know that wine is specifi- ... lighter than water, and the lighter

body will always be uppermost; upon these principles, I will exhibit two or three experiments. I have filled the bulb B (Plate III. Fig. 23.) with the port wine to the top of the narrow stem *x*. I now fill A with water.

Emma. The wine is gradually ascending like a fine red thread through the water to its surface.

Father. And so it will continue till the water and wine have changed places.

Charles. I wonder the two liquids do not mix, as wine and water do in a common drinking glass.

Father. It is the narrowness of the stem *x* which prevents the admixture: in time, however, this would be effected, because water and wine have what the chemists call an attraction for each other.

Here is a small bottle B (Plate III. Fig. 24.) with a neck three inches long, and about one sixth of an inch wide; it is full of red wine. I will now place it at the bottom of a jar of water, a few inches

deeper than the bottle is high. The wine you observe is ascending through the water.

Emma. This is a very pretty experiment: the wine rises in a small column to the surface of the water, spreading itself over it like a cloud.

Father. Now reverse the experiment: fill the bottle with water, and plunge its neck quickly into a glass of wine; the wine is taking place of the water.

Charles. Could you decanter a bottle of wine in this way without turning it up?

Father. I could if the neck of the decanter were sufficiently small. The negroes in the West-Indies are said to be well acquainted with this part of hydrostatics, and that they plunder their masters of rum by filling a common bottle with water and plunging the neck of it into the bung-hole of the hogshead.

Emma. Poor creatures, they ought to have something to console them for the miseries they endure.

Father. Indeed the cruelties that are

in general exercised upon the slaves, very much extenuate the crime of pilfering of which they are said to be guilty.

Upon the principle of lighter fluids keeping the uppermost parts of a vessel, several fluids may be placed upon one another in the same vessel without mixing: thus in a long upright jar, three or four inches in diameter, I can place water first, then port wine, then oil, brandy, oil of turpentine, and alcohol.

Charles. How would you pour them in one upon another without mixing?

Father. This will require a little dexterity: when the water is in, I lay a piece of very thin pasteboard over its surface, and then pour in the wine; after which I take away the pasteboard, and proceed in the same manner with the rest. Take a common goblet or drinking glass, pour water in, and then lay a thin piece of toasted bread upon the water, and you may pour your wine upon the bread and the two fluids will remain for some time separate.

Emma. Is the toast placed merely to receive the shock of the wine when poured in?

Father. That is the reason. Now I will proceed to explain the principle of the *hydrometer*, an instrument contrived to ascertain with accuracy and expedition the specific gravities of different fluids.

A B (Plate III. Fig. 25.) is a hollow cylindrical tube of glass, ivory, copper, &c. five or six inches long, annexed to a hollow sphere of copper D: to the bottom of this is united a smaller sphere E, containing a little quicksilver, or a few leaden shot sufficient to poise the machine, and make it sink vertically in the fluid.

Charles. What are the marks on the tube?

Father. They are degrees exhibiting the magnitudes of the part below the surface, consequently the specific gravity of the fluid in which it descends. If the hydrometer, when placed in water, sink to the figure 10, and in spirit of wine to 11.1, h en the specific gravity of the water is

to that of the spirit, as 11.1 to 10: for if the same body float upon different fluids, the specific gravity of these fluids will be to each other *inversely* as the parts of the body immersed.

Emma. By *inversely*, do you mean that the fluid in which the hydrometer sinks the deepest is of the least specific gravity?

Father. Yes, I do: here is a piece of dry oak, which if I put into spirits of wine is entirely immersed; in water the greatest part of it sinks below the surface; but in mercury it scarcely sinks at all. Hence it is evident that the hydrometer will sink deepest in the fluid that is of the least specific gravity.

To render this instrument of more service, a small stem is fixed at the end of the tube, upon which weights like that at g may be placed. Suppose then the weight of the instrument is 10 dwts., and by being placed in any kind of spirit it sinks to a certain point L, it will require an additional weight, suppose 1.6 dwt. to cause it to

is a certain chemical union or penetration between the particles of the two fluids, so that they will not make a quart. This subject we shall resume in our chemical conversations.*

* See Dialogues in Chemistry, Vol. I. p. 45.

CONVERSATION XVII.

Of the Hydrometer, and Swimming.

CHARLES. To what purposes is the hydrometer applied?

Father. It is used in breweries and distilleries to ascertain the strength of their different liquors: and by this instrument the excise officers gauge the spirit, and thereby determine the duties to be paid to the revenue.

I think from the time we have spent in considering the specific gravity of different bodies, you will be at no loss to account for a variety of circumstances that will present themselves to your attention in the common

concerns of life. Can you, Emma, explain the theory of floating vessels?

Emma. All bodies whatever that float on the surface of the water displace as much fluid as is equal in weight to the weight of the bodies: therefore, in order that a vessel may keep above water, it is only necessary to take care that the vessel and its cargo, passengers, &c. should be of less weight than the weight of a quantity of water equal in bulk to that part of the vessel which it will be safe to immerge in the water.

Father. Salt water, that is, the water in the sea is specifically heavier than fresh or river water.

Charles. Then the vessel will not sink so deep at sea as it does in the Thames.

Father. That is true; if a ship is laden at Sunderland, or any other sea-port, with as much coals or corn as it can carry, it will come very safely till it reaches the fresh water in the Thames, and there it will infallibly go to the bottom unless some of the cargo be taken out.

Emma. How much heavier is sea water than the fresh?

Father. About one thirtieth part, which would be a guide to the master of a vessel, who was bent upon freighting it as deeply as possible.

Charles. In bathing, I have often tried to swim, but have not yet been able to accomplish the task; is my body specifically heavier than the water?

Father. I hope you will learn to swim, and well too; it may be the means of saving your own life, and rescuing others who are in danger of drowning:

————Life is oft preserv'd
By the bold swimmer in the swift illapse
Of accident disastrous.

THOMSON.

By some very accurate experiments made by Mr. Robertson, the late librarian of the Royal Society, upon ten different persons,

the mean specific gravity of the human body was found to be about ⅙th less than that of common river water.

Charles. Why then do I sink to the bottom? I ought to swim like wood on the surface.

Father. Though you are specifically lighter than water, yet it will require some skill to throw yourself into such a position as to cause you to float like wood.

Charles. What is that position?

Father. Dr. Franklin recommends a person to throw himself in a slanting position on his back, but his whole body, except the face, should be kept under water. And Thomson describes a youth swimming, who

——————through the obedient wave,
At each short breathing by his lip repell'd,
With arms and legs according well, he makes,
As humour leads, an easy winding path.

SUMMER.

Unskilful persons in the act of attempting this are apt to plunge about and struggle: by this means they take water in at their mouths and nostrils, which of itself would soon render them as heavy or heavier than the water. Moreover the coldness of the stream tends to contract the body; perhaps fear has the same tendency; all these things put together will easily account for a person sinking in the water.

Emma. But if a dog or cat be thrown into the pond they seem as terrified as I should be in a like situation, yet they never fail of making their way out by swimming.

Father. Of all land animals, man is, probably, the most helpless in this element. The brute creation swim naturally, the human race must acquire the art by practice. In other animals the trunk of the body is large, and their extremities small: in man it is the reverse, the arms and legs are small in proportion to the bulk of the

body, but the specific gravity of the extremities is greater than that of the trunk, consequently it will be more difficult for man to keep above water than for four-footed animals: besides, the act of swimming seems more natural to them than to us, as it corresponds more nearly to their mode of walking and running than to ours.

Charles. I will try the next time I bathe to throw myself on my back according to Dr. Franklin's directions.

Father. Do not forget to make your experiments in water that is not so deep as you are high by at least a foot, unless you have an experienced person with you: because an unsuccessful experiment in this element, where it is but a little out of your depth, may be the last you will make. And neither your sister nor I can spare you yet.

Charles. I once jumped into a part of the New River, which I thought did not ap-

pear deeper than you say, and I found it was over my head, but there were several persons there who soon put me in shallower water.

Father. It is not so generally known as it ought to be, that the depth of a clear stream of water is always one-fourth part greater than it appears to be.*

Charles. If the river appear to be only three feet deep, may I reckon upon its being full four feet?

Father. You must estimate it in this manner. Remember also that if a person sink slowly in water ever so deep, a small effort will bring him up again, and if he be then able to throw himself on his back, keeping only his face above water, all will be well;†

* The reason of this deception is explained in our Conversations on Optics. See Vol. II. Conversation IV.

† It has been asserted lately, in some of our best periodical works, that if a person falling in the water, has

but if instead of this he is alarmed, and by struggling throw himself so high above the water that his body does not displace so much of it as is equal to its weight, he will sink with an accelerated motion: a still stronger effort, which the sense of danger will inspire, may bring him up again, but in two or three efforts of this kind his strength fails, and he sinks to rise no more alive.

Emma. Is it the upward pressure which brings up a person that is at a considerable depth in the water?

Father. It is: this upward pressure balances the weight of water which he sustains, or he would be crushed to pieces by it.

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presence of mind to lean his head a little backwards and never lift his hands above the water, he cannot sink.

Cork an empty bottle ever so well, and with weights plunge it down a hundred yards into the sea, and the pressure of the water will force the cork into the bottle.

CONVERSATION XVIII.

Of the Syphon.

FATHER. This bended tube (Plate III. Fig. 26.) is called a Syphon, and it is used to draw off water, wine, or other fluids, from vessels which it would be inconvenient to move from the place in which they stand.

Charles. I do not see how it can draw liquor out of any vessel:—why is one leg longer than the other?

Father. I will first show you how the operation is performed, and then endeavour to explain the principle.

I fill the tube, E D C with water, and

then placing a finger on F, and another on C, I invert the tube, and immerse the shorter leg into a jar of water; and having taken my fingers away, you see the water runs over in a stream.

Emma. Will it continue to flow over?

Father. It will till the water in the vessel comes as low as E, the edge of the syphon.

Charles. Is this accounted for by pressure?

Father. To the pressure or weight of the atmosphere we are indebted for the action of the syphon, pumps, &c. At present you must take it for granted that the air which we breathe, though invisible, has weight, and that the pressure, occasioned by it, is equal to about 14 or 15 pounds upon every square inch.* The surface of this

* If any of my young readers are unwilling to admit this assertion without proof, they must be referred to the middle of the second volume of these Dialogues, for a complete demonstration of the fact.

table is equal to about six square feet, or 864 square inches, and the pressure of the atmosphere upon it is equal to at least 12,000 pounds.

Emma. How does the pressure of the air cause the water to run through the syphon?

Father. The principle of the syphon is this; the two legs are of unequal length, consequently the weight of water in the longer leg is greater than that in the shorter, and therefore will, by its own gravity, run out at C, leaving a vacuum from D to E, did not the pressure of the atmosphere on the surface of the water in the jar force it up the leg D E, and thus continually supply the place of the water in D C.

Charles. But since the pressure of fluids acts in all directions, is not the upward pressure of the atmosphere against C, the mouth of the tube, equal to the downward pressure on the surface of the water?

Father. The pressure of the atmosphere may be considered as equal in both cases.

but these equal pressures are counteracted by the pressures of the two unequal columns of water, D E and D C. And since the atmospheric pressure is more than sufficient to balance both these columns of fluid, that which acts with the lesser force, that is, the column D E will be more pressed against D C than D C is against D E at the vertex D; consequently the column D E will yield to the greater pressure, and flow off through the orifice C.

Emma. Would the same thing happen if the outer leg D C were shorter than the other?

Father. If D C were broken off at B, even with the surface of the water, no water would run over: or if it were broken off any where lower than B, it would only run away till the surface of the fluid descended to a level with the length of the outer tube, because then the column D E will be no more pressed against D C, than D C is against D E, and consequently the syphon will empty itself; the water in the outer leg will run

out at the lower orifice, and that in the inner will fall back into the jar.

Charles. In decanting a bottle of wine are you obliged first to fill the syphon with liquor, and then invert it?

Father. No: a small pipe is fixed to the outer leg of the syphon, by which the air is drawn out of it by the mouth, and the short leg being immersed in the wine, the fluid will follow the air, and run out till the bottle is empty.

The syphon is sometimes disguised for the sake of amusing young people. Tantalus's cup (Plate III. Fig. 27.) is of this kind. The longer leg of the syphon passes through, and is cemented into the bottom of the cup; if water be poured into the cup, so as not to stand as high as the bend of the tube, the water will remain as in any common vessel; but if it be raised over the bended part of the syphon, it will run over and continue to run till the vessel is emptied. Sometimes a little figure of a man, representing Tantalus, conceals the syphon, so

that Tantalus, as in the fable, stands up to his chin in water, but is never able to quench his thirst, for just as it comes to a level with his chin, it runs out through the concealed syphon.

Emma. To this fable the lines in Pope's Homer refer:

'E'en in the circling floods refreshment craves,
And pines with thirst amidst a sea of waves;
And when the water to his lips applies,
Back from his lips the treacherous water flies.

POPE.

Father. It is alluded to also by our own Milton:

————and of itself the water flies
All taste of living wight, as once it fled
The lip of Tantalus.———

Par. Lost, Book II.

This is another kind of Tantalus's cup (Plate IV. Fig. 28.) but the syphon is c-

cealed in the handle, and when the water in the cup, which communicates with the shorter leg at I, is raised above the bend of the handle, it runs out through the longer leg at P, and so continues till the cup is empty. This cup is often made to deceive the unwary, who, by taking it up to drink, cause the water, which was, while at rest, below the bend of the syphon, to run over, and then there is no means of stopping the stream till the vessel is empty.

Charles. I have frequently seen at the doors of public houses large hogsheads of spirits in carts or waggons, and persons drawing off the contents by means of an instrument like a syphon.

Father. That is called a distiller's crane or syphon. B (Plate IV. Fig. 29.) represents one of these barrels with the crane at work from the bung-hole *n*. The longer leg *m r* is about three feet long, with a stop-cock near the middle, which must be shut, and then the shorter leg is immersed in the liquor.

Emma. Is the air in the short leg forced into the other by the upward pressure of the fluid?

Father. It is, and the cock being shut it cannot escape, but will be very much condensed. If then the cock be suddenly opened, the condensed air will rush out, and the pressure of the air on the liquor in the vessel will force it over the bend of the syphon, and cause it to flow off in a stream, as the figure represents. If, however, the barrel be not full, or nearly so, then it is necessary to draw the air out of the syphon by means of a small tube, *a b*, fixed to it.

By the principle of the syphon we are enabled to explain the nature of intermitting springs.

Emma. What are these, Papa?

Father. They are springs or rather streams, that flow periodically. A figure will give a clearer idea of the subject than many words without. G F C (Plate IV. Fig. [illegible]) represent a cavity in the bowels of a hill, or mountain, from the bottom of which

C, proceeds the irregular cavity C E D, forming a sort of natural syphon. Now, as the cavity fills, by means of rain or snow draining through the pores of the ground, the water will gradually rise in the leg C E, till it has attained the horizontal level *h h*, when it will begin to flow through the leg E D, and continue to increase in the quantity discharged as the water rises higher, till a full stream is sent forth, and then, by the principle of the syphon, it must continue to flow till the water sink to the level *i i*, when the air will rush into the syphon, and stop its motion.

Charles. And being once brought so low, it cannot run over again till the cavity is full of water, or, at least, up to the level *h h*, which, as it is only supplied by the draining of the water through the ground, must take a considerable length of time: Is that the reason why they are called intermitting springs?

Father. It is: Mr. Clare, in his treatise "On the Motion of Fluids," illustrates this

subject by referring to a pond at Gravesend, out of which the water *ebbs* all the time the tide is coming into the adjacent river, and runs in while the tide is going out. Another instance mentioned by the same author is a spring in Derbyshire, called the Wedding-well, which, at certain seasons, issues forth a strong steam, with a singing noise, for about three minutes, and then stops again. At Lambourn, in Berkshire, there is a brook which in summer carries down a stream of water sufficient to turn a mill; but during the winter there is scarcely any current at all.

In intermitting springs the periodical returns of the flowing and cessation will be regular, if the filling of the reservoir be so; but the interval of the returns must depend on the quantity of water furnished by the springs.

CONVERSATION XIX.

Of the Diver's Bell.

FATHER. Take this ale-glass, and thrust it with the mouth downwards into a glass jar of water, and you will perceive that but very little water will enter into it.

Charles. The water does not rise in it more than about a quarter of an inch: if I properly understand the subject, the air, which filled the glass before it was put in water, is now compressed into the smaller space; and it is this body of air that prevents more water from getting into the glass.

Father. That is the reason: for if you tilt the glass a little on one side, a part of the air will escape in the form of a bubble, and then the water will rise higher in the glass.

Upon this simple principle machines have been invented, by which people have been able to walk about at the bottom of the sea, with as much safety as upon the surface of the earth. The original machine of this kind was much improved by Dr. Halley, more than a century ago: it was called the Diver's Bell.

Charles. Was it made in the shape of a bell?

Father. It was; and as great strength was required to resist the pressure of the water, he caused it to be made of copper: this (Plate IV. Fig. 31.) is a representation of it. The diameter of the bottom was five feet, that of the top three feet, and it was eight feet high: to make the vessel sink vertically in water, the bottom was loaded with a quantity of leaden balls.

Emma. It was as large as a good sized closet; but how did he contrive to get light?

Father. Light was let into the bell by means of strong spherical glasses, fixed in the top of the machine. They are thus described by Dr. Darwin:

————Lo! Britain's sons shall guide
Huge sea-balloons beneath the tossing tide;
The *diving* castles, roof'd with spheric glass,
Ribb'd with strong oak, and barr'd with bolts of brass.

Botanical Garden.

Charles. How are the divers supplied with air?

Father. Barrels, filled with fresh air, were made sufficiently heavy, and sent down, such as that represented by c; from which a leathern pipe communicated with the inside of the bell, and a stop-cock at the upper part of the bell let out the foul

air. Dr. Darwin, in the spirit of prophecy, anticipates the time when these machines will be sent upon voyages of discovery, and says,

Then shall Britannia rule the wealthy realms,
Which Ocean's wide, insatiate wave o'erwhelms;
Confine in netted bowers his scaly flocks,
Part his blue plains, and people all his rocks.

Botanical Garden.

Emma. The little men seem to sit very contentedly under the bell, yet I do not think I should like a journey with them.

Father. Perhaps not: but the principal inconvenience which divers experience arises from the condensation of the air in the bell, which though in the ale-glass was very trifling, yet at considerable depths in the sea is very great, and produces a disagreeable pressure upon all parts of the body, but more particularly in their ears, as if quills were thrust into them. This

sensation does not last long, for the air pressing through the pores of the skin, soon becomes as dense within their bodies as without, when the sense of pressure ceases.

Emma. They might stop their ears with cotton.

Father. One of them once thought himself as cunning as you, and for the want of cotton he chewed some paper, and stuffed it into his ears; as the bell descended, the paper was forcibly pressed into the cavities, and it was with great difficulty and some danger, that it was extracted by a surgeon.

Charles. Are divers able to remain long under water?

Father. Yes: when all things are properly arranged, if business require it, they will stay several hours without the smallest difficulty.

Emma. But how do they get up again?

Father. They are generally let down from on board ship, and taking a rope with

them, to which is fixed a bell in the vessel, they have only to pull the string, and the people in the ship draw them up.

Charles. What does the figure E represent?

Father. A man detached from the bell, with a kind of inverted basket made of lead, in which is fixed another flexible leathern pipe, to give him fresh air from the bell as often as he may find it necessary. By this method a man may walk to the distance of 80 or 100 yards from the machine.

Emma. It is to be hoped his comrades will not forget to supply him with air.

Father. If his head is a little above that part of the bell to which the pipe communicates, he can by means of a stop-cock assist himself as often as he requires a new supply; and that man is always best helped who can help himself.

Charles. I dare say that is a right principle; in the present case, I am sure, it would be exceedingly wrong to depend on

another for that which might be done by one's self. Has the Diver's Bell been applied to any very useful purposes?

Father. By means of this invention, a great number of valuable commodities have been recovered from wrecks of ships, though at great depths in the sea.

CONVERSATION XX.

Of the Diver's Bell.

FATHER. You see how, by this contrivance the parts of wrecked vessels and their cargoes are saved from the devouring ocean; and by what means people are enabled to pursue the business of pearl and coral fishing.

Emma. Have there been no accidents attending this business?

Father. There are very few professions, however simple, the exercise of which, either through carelessness or inattention, is not attended with danger. The diving-bell proved fatal to Mr. Spalding and an

assistant, who went down to view the wreck of the Imperial East-Indiaman near Ireland. They had been down twice, but on descending the third time they remained about an hour under water, and had two barrels of air sent down to them, but the signals from below not being again repeated, after a certain time they were drawn up by their assistants, and both found dead in the bell. This accident happened by the twisting of some ropes, which prevented the unfortunate sufferers from announcing their wants to their companions in the ship.—Mr. Day also perished at Plymouth in a diving-bell of his own construction, in which he was to have continued, for a wager, twelve hours, one hundred feet deep in water. To these Dr. Darwin alludes; when speaking of the sea he says,

> Mingling in death the brave and good behold,
> With slaves to glory, and with slaves to gold,
> Shrin'd in the deep shall DAY and SPALDING mourn,
> His treacherous bell, sepulchral urn!
>
> BOTANICAL GARDEN.

Charles. Did these accidents put an end to the experiments?

Father. No; but they have led to improvements in the structure and use of the machine. Mr. Smeaton very successfully made use of a square cast-iron chest (Plate IV. Fig. 32.) the weight of which 50 cwt. was heavy enough to sink itself. It was $4\frac{1}{2}$ feet in height, the same number of feet in length, and 3 feet wide, and of course afforded sufficient room for two men to work under it at a time.

Emma. What are those round things at the top?

Father. They are four strong pieces of glass to admit the light. The great advantage which this had above Dr. Halley's bell, was, that the divers were supplied with a constant influx of air, without any attention of their own, by means of a forcing air-pump, worked in a boat upon the water's surface.

Charles. That is not represented in the plate.

Father. Look to the next figure, (Plate IV. Fig. 33.) which is a diving machine of a different construction, invented by the very ingenious and truly respectable lecturer, Mr. Adam Walker,* by whose leave I am enabled to copy the figure.

This machine is of the shape of a conical tub, but little more than one-third as large as Mr Smeaton's. The balls at the bottom are lead, sufficiently heavy to make it sink of itself: a bended metal tube, *a b c*, is attached to the outside of a machine with a stop-cock *a*, and a flexible leathern tube to the other end *c*; this tube is connected with a forcing air-pump *d*, which abundantly supplies the diver with fresh air.

Emma. Can he move about with the machine?

Father. Most readily; for the pressure of the water being equal on all sides, he

* See Walker's System of Natural Philosophy, 2 ls. 4to.

meets with very little resistance; and the ropes and leathern tube being flexible, he can, with the machine over his head, walk about several yards, in a perpendicular posture: and thus having a more ready access to pieces of the wreck than in a cumbrous bell, he can easily fasten ropes to them, and perform any sort of business nearly as well as on dry land. Mr. Walker says, that the greatest part of the wreck saved from the rich ship Belgioso was taken up by means of his bell. The following anecdote, given by this gentleman, will entertain my young readers.

"As the diver had plenty of air to spare, he thought a candle might be supported in the bell, and he could descend by night. He made the experiment, and presently found himself surrounded by fish, some very large, and many such as he had never seen before. They sported about the bell, and smelt at his legs as they hung in the water: this rather alarmed him, for he was not sure but some of the larger might take

a fancy to him; he therefore rang his bell to be taken up, and the fish accompanied him with much good nature to the surface."—To a scene not very unlike this, Dr. Darwin refers in the spirit of prophecy, when,

Onward, through bright meandering vales, afar,
Obedient sharks shall trail her sceptred car,
With harness'd necks the pearly flood disturb,
Stretch the silk rein, and champ the silver curb;
Pleas'd round her triumph wond'ring Tritons play,
And sea-maids hail her on the wat'ry way.

Botanical Garden.

CONVERSATION XXI.

Of Pumps.

FATHER. Here is a glass model of a common pump (Plate IV. Fig. 34.) which acts by the pressure of the atmosphere on the surface of the water in which it is placed.

Emma. Is this like the pump below stairs?

Father. The principle is exactly the same: *a* represents a ring of wood or metal, with pliable leather fastened round it to fit the cylinder A. Over the whole is a valve of metal covered with leather, of which a part serves as a hinge for the valve to open and shut by.

Charles. What is a valve, Sir?

Father. It may be described as a kind of lid or trap-door, that opens one way into a tube, but which the more forcibly it is pressed the other way, the closer the aperture is shut: so that it either admits the entrance of a fluid into the tube, and prevents its return; or permits it to escape, and prevents its re-entrance.

Attend now to the figure: the handle and rod *r* end in a fork *s*, which passes through the piston, and is screwed fast to it on the under side. Below this, and over a tube of a smaller bore, at *z*, is another valve *v* opening upward, which admits the water to flow up, but not to run down.

Emma. That valve is open now, by which we see the size of the lower tube, but I do not perceive the upper valve.

Father. It is supposed to be shut, and in this situation the piston *a* is drawn up, and being air-tight, the column of air on its is removed, and consequently leaves a

vacuum in the part of the cylinder between the piston and lower valve.

Father. I now see the reason of lifting up the pump-handle: because the piston then goes down to the lower valve, and by its ascent afterwards the vacuum is produced.

Charles. And the closer the piston is to the lower valve the more perfect will be the vacuum.

You know there is a pressure of the air on all bodies on or near the surface of the earth, equal to about 14 or 15 pounds on every square inch: this pressure upon the water in the well, into which the lower end of the pump is fixed, forces the water into the tube z above its level as high as *h*.

Charles. What becomes of the air that was in that part of the tube?

Father. You shall see the operation; I put the model into a dish of water which now stands at a level in the tube z, with the water in the dish. I draw up the piston B which causes a vacuum in the cylinder A.

Emma. But the valve *v* opens, and now the water has risen as high as *l*.

Father. Because when the air was taken out of the cylinder A, there was no pressure upon the valve *v* to balance that beneath it, consequently the air in the tube z opens its valve *v*, and part of it rushed into *a*. But as soon as part of the air had left the tube z, the pressure of the atmosphere upon the water in the dish was greater than that of the air in the tube, and therefore by the excess of pressure the water is driven into it as high as *l*.

Charles. The valve *v* is again shut.

Father. That is because the air is diffused equally between the level of the water at *l* and the piston *a*, and therefore the pressures over and under the valve are equal. And the reason that the water rises no higher than *l* is, that the air in that space is not only equally diffused, but is of the same density as the air without. Push down the piston *a* again.

Emma. I saw the valve in the piston open.

Father. For the air between the piston and valve *v* could not escape by any other means than by lifting up the valve in *a*. I will draw up the piston.

Charles. The water has risen now above the valve *v* as high as *m*.

Father. I dare say you can tell the cause of this.

Charles. Is it this: by lifting up the piston, the air that was between *l* and the valve *v* rushed into A, and the external pressure of the atmosphere forced the water after it?

Father. And now that portion of air remains between the surface of the water *m* and the piston. The next time the piston is forced down, all the air must escape, the water will get above the valve in the piston, and in raising it up again, it will be thrown out of the spout.

Emma. Will the act of throwing that out open the lower valve again, and bring in the fresh supply?

Father. Yes: every time the piston is elevated, the lower valve rises, and the up-

per valve falls; but every time the piston is depressed, the lower valve falls, and the upper one rises.

Emma. This method of raising water is so simple and easy that I wonder people should take the trouble of drawing water up from deep wells, when it might be obtained so much easier by a pump.

Father. I was going to tell you, that the action of pumps, so beautiful and simple as it is, is very limited in its operation. If the water in the well be more than 32 or 33 feet from the valve *v*, you may pump for ever, but without any effect.

Charles. That seems strange; but why 33 feet in particular?

Father. I have already told you that it is the weight of the atmosphere which forces the water into the vacuum of the pump: now if this weight were unlimited, the action of the pump would be so likewise; but the weight of the atmosphere is only about 14 or 15 pounds on every square inch; and [illegible]mn of water, of about 33 feet in height,

and whose surface is one square inch, weighs also 14 or 15 pounds.

Charles. Then the weight of the atmosphere would balance or keep in equilibrio only a column of water of 33 feet high, and consequently could not support a greater column of water, much less have power to raise it up.

Emma. A pump, then, would be of no use in the deep wells which we saw near the coast in Kent.

Father. None at all: the piston of a pump should never be sat to work more than 28 feet above the water, because at some period the pressure of the atmosphere is so much less than at others, that a column of water, something more than 28 feet will be equal to the weight of air.

You cannot better fix in your mind the principle and action of the pump, than by committing to your memory Dr. Darwin's beautiful description of it:

> NYMPHS! You first taught to pierce the secret caves
> Of humid earth, and lift her pond'rous waves;

Made with quick stroke the sliding piston bear
The viewless columns of incumbent air;—
Press'd by the incumbent air, the floods below
Through opening valves in foaming torrents flow;
Foot after foot with lessen'd impulse move,
And, rising, seek the vacancy above.

BOTANIC GARDEN.

CONVERSATION XXII.

Of the Forcing-pump—Fire engine—Rope-pump—and Water-press.

CHARLES. Why is this called the forcing-pump? (Plate IV. Fig. 35.)

Father. Because it not only raises the water into the barrel like the common pump, but afterwards forces it up into the reservoir K K.

Emma How is that operation performed, Papa?

Father. The pipe and barrel are the same as in the other pump, but the piston G has no valve; it is solid and heavy, and made air-tight, so that no water can get above it.

Charles. Does the water come up through the valve *a*, as it did in the last?

Father. By raising up the piston, or as it is generally called, the plunger G, a vacuum is made in the lower part of the barrel, into which, by the pressure of the air, the water rushes from the well, as you shall see.

Emma. And the valve is shut down.

Father. The water not being able to go back again, and being a fluid that is nearly incompressible, when the plunger is forced down, it escapes along the pipe M, and through the valve *b* into the vessel K.

Charles. Though the water stands no higher than *h*, yet it flows through the pipe F to some height.

Father. The pipe F *i* is fixed into the top of the vessel, and is made air-tight, so that no air can escape out of it after the water is higher than *i*, the edge of the pipe.

Emma. Then the whole quantity of air which occupied the space F *b* is compressed into the smaller space *h* F.

Father. You are right, and therefore the extra pressure on the water in the vessel forces it through the pipe, as you see.

Charles. And the greater the condensation, that is, the more water you force into the vessel E, the higher the steam will mount.

Father. Certainly: for the forcing-pump differs from the last in this respect, that there is no limit to the altitude to which water may be thrown, since the air may be condensed to almost any degree.

The water-works at London-bridge, alluded to p. 82, exhibit a most curious engine, constructed upon the principle of the forcing-pump: the wheel-work is so contrived as to move either way as the water runs: by these works, one hundred and forty thousand hogsheads of water are raised every day.

Emma. Is there any rule to calculate the height to which an engine will throw water?

Father. If the air's condensation be double that of the atmosphere, its pressure will raise water thirty-three feet; if the condensation be increased three-fold, the water will reach sixty-six feet; and so on, allowing the addition of thirty-three feet in height for every increase of *one* to the number that expressed the air's condensation.

Charles. Are fire-engines made in this manner?

Father. They are all constructed on the same principle, but there are two barrels by which the water is alternately driven into the air-vessels: by this means the condensation is much greater; the water rushes out in a continued stream, and with such velocity, that a raging fire is rather dashed out than extinguished by it, which is well described in the Botanic Garden:

NYMPHS! You first taught the gelid wave to rise,
Hurl'd in resplendent arches to the skies;
In iron cells condens'd the airy spring,
And imp'd the torrent with unfailing wing.
—On the fierce flames the showers impetuous falls,
And sudden darkness shrouds the shatter'd walls;
Steam, smoke, and dust, in blended volumes roll,
And night and silence re-possess the Pole,

Garden-engines are also constructed on a principle similar to that which we have been describing.

This figure (Plate IV. Fig. 36.) is the representation of a method of raising water from wells of considerable depth.

Emma. Is it a more convenient method than the wheel and axis?

Father. The wheel and axis are adapted merely to draw up water by buckets: whereas the rope-pump is intended to throw water into a reservoir to almost any height. It consists of three hair ropes passing over the pulleys A and B, which have three grooves in each. The lower pulley B is

immersed in the water, in which it is ke suspended by a weight *x*. The pulley are turned round with great velocity b multiplying wheels, and the cords in the ascent carry up a considerable quantity o water, which they discharge into the bo or reservoir *z*, from whence by pipes i may be conveyed elsewhere. The ropes must not be more than about an inch apart.

Emma. What is the reason of that, Papa?

Father. Because, in that case, a sort of column of water will ascend between the ropes, to which it adheres by the pressure of the atmosphere.

Charles. Ought not this column, in its ascent to fall back by its own gravity.

Father. And so it would, did not the great velocity of the ropes occasion a considerable rarefaction of the air near them, consequently the adjacent parts of the atmosphere pressing towards the vacuity, tend to support the water.

Emma. Can any considerable quantity of water be raised in this way?

Father. At Windsor a pump of this kind will raise, by the efforts of one man, about nine gallons of water in a minute from a well ninety-five feet deep. In the beginning of motion, the column of water adhering to the rope is always less than when it has been worked for some time, and the quantity continues to increase till the surrounding air partake of its motion. There is also another of these pumps at the same place, which raises water from the well in the round tower one hundred and seventy-eight feet in depth.

Charles. You told us some time ago, that when we had seen the nature and understood the construction of valves, you would explain the action of the water-press.

Father. This is a good time for the purpose, and with it I shall conclude our hydrostatical conversations.

You must turn back to the second Plate

(Fig. 14.) *a* is a strong cast-iron cylinder, ground very accurately within, that the piston *e* may fit exceedingly close and well. I need scarcely tell you, that the little figure represents a forcing-pump, with a solid plunger *c*, and a valve *n* that opens upwards, through which the water is brought into the pipe *n o*. By bringing down the plunger *c*, the water in *n o* is forced through the valve *x*, into the bottom of the cylinder, and thereby drives up the plunger *e*.

Charles. What does *m* represent?

Father. A bundle of hay, or bag of cotton, or any other substance that it may be desirable to bring into a compass twenty or thirty times less than it generally occupies.

Emma. I see now the whole operation: the more water there is forced into *n o*, the higher the plunger is lifted up, by which the substance *m* is brought into a smaller space.

Father. Every time the handle *s* is lifted up, the water rushes in from the well

cistern, and when it is brought down water must be forced into the cylin-r. The power of this engine is only ited by the strength of the materials of ch it is made, and by the force applied o it.

Mr. Walker says, a single man working at s, can, by a machine of this kind, bring hay, cotton, &c. into twenty times less compass than it was before; consequently a vessel carrying light goods may be made to contain twenty times more packages by means of the water-press than it could without its assistance.

PNEUMATICS:

CONVERSATION XXIII.

OF THE NATURE OF AIR.

Father——Charles——Emma.

FATHER. That branch of natural philosophy which is called Pneumatics, treats of the nature, weight, pressure, and spring of the air which we breathe, and of the several effects dependent upon these properties.

Charles. You told us a few days ago, that the air, though to us invisible, is a fluid: but it surely differs very much from those fluids which you conversed upon when treating of hydrostatics.

Father. It does so: but recollect the terms by which we defined a fluid.

Charles. You distinguished a fluid as a body, the parts of which yield to the least pressure.

Father. The air, in which we live and move, will answer to this definition; since we are continually immersed in it, as fish are in the water; if the parts did not yield to the least force, we should be constantly reminded of its presence by the resistance made to our bodies; whereas persons unaccustomed to think on these subjects are not even aware that they are surrounded with a fluid, the weight and pressure of which if, not counterbalanced by some other power, would instantly crush the human frame.

Emma. In a still, calm day, such as the present is, when one can scarcely discern a single leaf in motion, it is difficult to conceive of the existence of such a fluid; but when

——————down at once
Precipitant, descends a mingled mass
Of roaring winds, and flames, and rushing floods,
(THOMSON'S SUMMER)

no doubt can remain as to the existence of some mighty unseen power.

Charles. By this quotation, Emma, you take it for granted that the air and the winds are the same.

Father. This is really the fact, as we shall prove on a future day.

Charles. But I am not quite satisfied that the air is such a body as you have described.

Father. I do not wish to proceed a single step till I have made your mind easy upon this head.——You see how easily those gold and silver fish move in the water: can you explain the reason of it?

Charles. Is it not by the exertion of their fins?

Father. A fish swims by the help of his fins and tail; and fish in general are nearly of the same specific gravity with water. Take away the water from the vessel, and the fish would still have the use of their fins and tail, at least for a short period.

Emma. And they would flounder about at the bottom.

Father. Now consider the case of birds, how they fly; the swallow for instance, glides as smoothly along in the air, as fish do in the water: but if I were to put a bird, or even a butter-fly, under a glass receiver, however large, and take away the air, they would have no more use of their wings, than fish have of their fins when out of water. You shall see the experiment in a day or two:

———————If this support
Were wanting, all the feather'd tribes must drop
The useless wing.

Eudosia.

Emma. And would they die in this situation, as fish die when taken from their natural element, the water?

Father. The cases are precisely similar: some fish, as the carp, the eel, and almost all kinds of shell-fish, will live a considerable time out of water; so some creatures, which depend upon air for existence, will live a long time in an exhausted receiver; a butterfly, for instance, will fall to the bottom apparently lifeless, but admit the air again into the receiver, and it will revive; whereas experiments have been made on mice, rats, birds, rabbits, &c. and it is found that they will live without air but a very few minutes.

Emma. These are very cruel experiments.

Father. And ought by no means to be indulged in; they can be only justified upon the presumption, that in the hands, and under the direction of able philosophers, they may lead to discoveries of importance

to the health and happiness of the human race.

Charles. Can fish live in water from which the air is wholly excluded?

Father. The air is, in fact, as necessary to their existence as it is to ours. Besides their fins, fish have the use of an air-vessel, which gives them full command of their various motions in all depths of water, which their fins without it would not be equal to.

Emma. What do you mean by an air-vessel?

Father. It is a small bladder of air, so disposed within them, that, by the assistance of their muscles, they are able to contract and dilate it at pleasure. By *contraction* they become specifically heavier than the water, and sink; by *dilatation* they are lighter, and rise to the surface more readily.

Charles. Are these operations effected by the external air?

Father. Very much so: for if you take away the air from the water in which a fish is swimming, it will no longer have the power of contracting the air-vessel within, which will then become so expanded as to keep it necessarily on the surface of the water, evidently to its great inconvenience and pain.

CONVERSATION XXIV.

Of the Air-Pump.

EMMA. You have told us, Papa, of taking away the air from vessels; will you show us how that is performed?

Father. I will; and I believe it will be the most convincing method of proving to you that the air is such a body as I have described.

This instrument (Plate v. Fig. 1.) is called an air-pump, and its use is to exhaust or draw away the air from any vessel, as the glass receiver L K.

Charles. Does it act like the common pu---

Father. So much so, that if you comprehend the nature and structure of the one, you will find but little difficulty in understanding the other. I will, however, describe the different parts. A A are two strong brass barrels, within each of which, at the bottom, is fixed a valve, opening upwards; these valves communicate with a concealed pipe that leads to K. The barrels include also moveable pistons, with valves opening upwards.*

Emma. How are they moved?

Father. To the upper parts of the pistons is attached rack-work, part of which you see at C C: these racks are moved up and down by means of a little cog-wheel, turned round by the handle R.

Charles. You turn the handle but half way round.

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* The reader is supposed to have attended to the structure of the common pump, described in Hydrostatics. Conversation XXI.

Father. And by so doing, you perceive that one of the racks rises, and the other descends.

Emma. What is the use of the screw v?

Father. It serves to re-admit air into the receiver when it is in a state of exhaustion; for without such a contrivance, the receiver could never be moved out of its place, after the air was once taken from beneath it. But you shall try for yourselves. I first place a slip of wet leather under the edge of the receiver, because the brass plate is liable to be scratched, and the smallest unevenness between the receiver and plate would prevent the success of our experiment.—I have turned the handle but a few times: try to take away the receiver.

Charles. I cannot move it.

Father. I dare say not: for now the greater part of the air is taken from under the receiver, consequently it is pressed down with the weight of the atmosphere on the outside.

Emma. Pray explain how the air was taken away.

Father. By turning the winch R half way round, I raise one of the pistons, and thereby leave a vacuum in the lower part of the barrel, and a portion of the air in the receiver rushes through the pipe into the empty barrel. I then turned the winch the other way, which raised the other piston, and a vacuum would be left in that barrel, did not another portion of air rush from the receiver into it.

Charles. When the first piston descended, did the air in the barrel open the little valve, and escape by the rack C?

Father. It did: and by the alternate working of the pistons, so much of the air is taken away, that the quantity left has not force enough to raise the valve.

Charles. Cannot you take all the air from the receiver?

Father. Not by means of the air-pump.

Emma. What is the reason that a mist comes on the inside of the glass receiver while the air is exhausting?

Father. It is explained by the sudden expansion of the air that is left in the receiver, which we shall notice more particularly in our conversations on Chemistry. The fact is described, as well as the general operations of the air-pump, by Dr. Darwin.

——How, as in brazen pumps the pistons move,
The membrane valve sustains the weight above,
Stroke follows stroke, the gelid vapour falls,
And misty dew-drops dim the crystal walls;
Rare and more rare expands the fluid thin,
And silence dwells with vacancy within.

BOTANIC GARDEN.

The last line alludes to a fact hereafter to be explained,* namely, that where there is no air, there can be no sound.

Charles. You have not told us the use

* See Conversation XXXII.

of the smaller receiver *w*, with the bottle of quicksilver within it.

Father. By means of the concealed pipe there is a communication between this and the large receiver, and the whole is intended to show to what degree the air in the large receiver is exhausted. It is called the small barometer-gauge, the meaning of which you will better understand when the structure of the barometer is explained.—I will now show you an experiment or two, by which the resistance of the air is clearly demonstrated.

Emma. Are these mills (Plate v. Fig. 2.) for the purpose?

Father. Yes, they are: the machine consists of two sets of vanes, *a* and *b*, made equally, and to move on their axes with the same freedom.

Charles. But the vanes of *a* are placed edgeways, and those of *b* are breadthways.

Father. They are so placed to exhibit in a striking manner the resistance of the atmosphere; for as the little mill *a* turns, it is resisted only in a small degree, and

will go round a much longer time than the other, which, in its revolutions, meets the air with its whole surface. By means of the spring *c* resting against the slider *d* in each mill, the vanes are kept fixed.

Emma. Shall I push down the sliders?

Father. Do so: you see that both set off with equal velocities.

Charles. The mill *b* is evidently declining in swiftness, while the other goes on as quick as ever.

Father. Not quite so: for in a few minutes you will find them both at rest.

Now we will place them under the receiver of the air-pump, and by a little contrivance we shall be able to set the mills a going after the air is exhausted from the receiver; and then, as there is no sensible resistance against them, they will both move round a considerable time longer than they did in the open air, and the instant that one stops, the other will stop also.

Emma. This experiment clearly shows the resisting power of the air.

Father. It shows also that its resistance is in proportion to the surface opposed to it: for the vane which met and divided the air by the edge only, continued to move the longest, while they were both exposed to it; but when that was removed, they both stop together, because there is nothing now to retard their motion, but the friction on the pivots, which is the same in both cases. Take this guinea and a feather; let them both drop from your hand at the same instant.

Charles. The guinea is soon at rest at my feet, but the feather continues floating about. Is the feather specifically lighter than air?

Father. No: for if it were, it would ascend till it found the air no heavier than itself; whereas, in a minute or two, you will see the feather on the floor as well as the guinea: it is however so light, and presents so large a surface to the air, in comparison to its weight, that it is considerably longer in falling to the ground than

heavier bodies, such as a guinea. Take away the resisting medium, and they will both reach the bottom at once.

Emma. How will you do that?

Father. Upon this brass flap (Plate v. Fig. 3.) I place the guinea and the feather, and having turned up the flap, and shut it into a small notch, I fix the whole on a tall receiver, with a piece of wet leather between the receiver and brass. I will now exhaust the air from under the receiver, by placing it over the air-pump, and if I turn the wire *f* a little, the flap will slip down, and guinea and feather will fall with equal velocities:

———————In perfect void
All substances with like velocity
Descend; nor the soft down outstrips the gold.
EUDOSIA.

Charles. They are both at the bottom, but I did not see them fall.

Father. While I repeat the experiment, you must look stedfastly to the bottom,

because the distance is too small for you to trace their motion; but by keeping your eye at the bottom you will see the feather and guinea arrive at the same instant.

In this glass tube (Plate v. Fig. 4.) is some water, but the air is taken away, and the glass completely closed. Turn it up quick, so that the water may fall on the other end.

Emma, It makes a noise like the stroke of a hammer.

Father. And for that reason it is usually called the philosophical hammer. The noise is occasioned through the want of air to break the fall: for if I take another glass in all respects like it, but having air enclosed in it, as well as water, you may turn it as often as you please with hardly any noise.

CONVERSATION XXV.

Of the Torricellian Experiment.

CHARLES. If by means of the air-pump you cannot perfectly exhaust the air from any vessel, by what means is it done?

Father. This glass tube is about 36 inches long, and open at one end only. I fill it very accurately with quicksilver, and placing my thumb over the open end, I invert the tube, and plunge it into a vessel of the same metal, taking care not to remove my thumb till the end of the tube is completely immersed in quicksilver.—You observe the mercury is suspended in the tube in height, and above it there is a

perfect vacuum; that is, the six or seven inches at the upper part of the tube the air is perfectly excluded.

Emma. Could not the air get in when you took away your thumb?

Father. You saw that I did not remove my thumb till the open end of the tube was wholly under the quicksilver, therefore no air could get into the tube without first descending through the quicksilver: now you know that a lighter fluid will not descend through one that is heavier, and consequently it is impossible that any air should be in the upper part of the tube.

Charles. What makes the quicksilver stand at that particular height?

Father. Before I answer this, tell me the reason why water cannot be raised by means of a common pump if the piston be higher than about 32 or 33 feet? from the water.

Charles. Because the pressure of the atmosphere is equal to the pressure of a column of water so many feet in height.*

* See Conversation. XXI.

Father. And the pressure of a column of quicksilve twenty-nine or thirty inches long, a little more or less according to the variation of the air, is equal to the pressure of a column of water thirty-two or thirty-three feet high, and consequently equal to the pressure of the whole height of the atmosphere.

Emma. Is then the mercury in the tube kept suspended by the weight of the air pressing on that in the cup?

Father. It is.

Emma. If you could take away the air from the cup, would the quicksilver descend in the tube?

Father. If I had a receiver long enough to enclose the cup and tube, and were to place them on the air-pump, you would see the effect that a single turn of the handle would have on the mercury; and, after a very few turns, the quicksilver in the tube would be nearly on a level with that in the cup.

I can show you by means of this syringe, that the suspension of the quicksilver in the tube is owing to nothing but the pressure of the air.

Charles. What is the structure of the syringe?

Father. If you understand in what manner a common water-squirt acts, you will be at no loss about the syringe, which is made like it.

Charles. By dipping the small end of a squirt in water, and lifting up the handle, a vacuum is made, and then the pressure of the air on the surface of the water forces it into the squirt.

Father. That is the proper explanation. —This vessel D, (Plate V. Fig. 5.) containing some quicksilver, and the small tube *g f*, 33 inches long, open at both ends, immersed in it, are placed under a large receiver A B, the brass plate C, put upon it with a piece of wet leather, admits the small tube to pass through it at *h*. I will now screw the syringe H on the tube *g f*, and by lift-

ing up the handle I, a partial vacuum is made in the tube, consequently the pressure of the air in the receiver upon the mercury in the cup D forces it up into the little tube as high as *x*, just in the same manner as water follows the piston in a common pump.

Emma. But is not this rise of the quicksilver in the tube owing to the suction of the syringe?

Father. To prove to you that it is not, I place the whole apparatus over the air-pump, and exhaust the air out of the receiver A B. This operation, you must be sensible, has not the smallest effect on the air in the syringe and little tube; but you nevertheless observe, that the mercury has again fallen into the cup D; and the syringe might now be worked for ever without raising the mercury in the tube; but admit the air into the receiver, and its action upon the surface of the quicksilver in the cup will force it instantly into the tube.

This is called the Torricellian experi-

ment, in honour of Torricelli, a learned Italian, and disciple of Galileo, who invented it, and who was the first person that discovered the pressure and weight of the air.

CONVERSATION XXVI.

Of the Pressure of the Air.

CHARLES. It seems very surprising that the air, which is invisible, should produce such effects as you have described.

Father. If you are not satisfied with the evidence which your eyes are capable of affording, you would perhaps have no objection to the information which your feelings may convey to your mind. Place this little glass A B, open at both ends (Plate v. Fig. 6.), over the hole of the pump plate, and lay your hand close upon the top B, while I ndle of the pump a few times.

Charles. It hurts me very much: I cannot take my hand away.

Father. By letting in the air, I have released you. The pain was occasioned by the pressure of the air on the outside of your hand, that being taken away from under it, which served to counterbalance its weight.

This is a larger glass of the same kind (Plate v. Fig. 7.); over the large end, I tie a piece of wet bladder very tight, and will place it on the pump, and take the air from under it.

Emma. Is it the weight of air that bends the bladder so much?

Father. Certainly: and if I turn the handle a few more times it will burst.

Charles. It has made a report as loud as a gun.

Father. A piece of thin flat glass may be broken in the same manner.—Here is a glass bubble A, with a long neck (Plate v. Fig. 8.), which I put into a cup of water B,

and place them under a receiver on the plate of the air-pump, and by turning the handle, the air is not only taken from the receiver, but that in the hollow glass ball will make its way through the water and escape.

Emma. Is it the air which occasions the bubbles at the surface of the water?

Father. It is. Now the bubbling is stopped, and therefore I know that as much of the air is taken away as can be got out by means of the pump. The hollow ball is still empty: but by turning the cock v of the pump (Fig. 1.) the air rushes into the receiver and presses upon the water, thereby filling the ball with the fluid.

Charles. It is not quite full.

Father. That is because the air could not be perfectly exhausted, and the little bubble of air at the top, is what, in its expanded state, filled the whole glass ball, and now by the pressure of the external air it is reduced into the size you see it.

Another very simple experiment will con- [illegible] you that suction has nothing to do [illegible] e experiments. On the leather of

the air-pump, at a little distance from the hole, I place lightly this small receiver x, and pour a spoonful or two of water round the edge of it (Plate v. Fig. 9.) I now cover it with a larger receiver A B, and exhaust the air.

Emma. I see by the bubbles round the edge of the small receiver that the air is making its way from under it.

Father. I have pretty well exhausted all the air; can you move the large receiver?

Charles. No: but by shaking the pump, I see the little one is loose.

Father. The large one is rendered immoveable by the pressure of the external air. But the air being taken from the inside of both glasses, there is nothing to fasten down the smaller receiver.

Emma. But if suction had any thing to do with this business, the little receiver would be fast, as well as the other.

Father. Turn the cock v of the air-pump quickly. You hear the air rushing in with violence.

Charles. And the large receiver is loosened again.

Father. Take away the smaller one, Emma.

Emma. I cannot move it with all my strength.

Father. Nor could you lift it up if you were a hundred times stronger than you are. For by admitting the air very speedily into the large receiver, it pressed down the little one before any air could get underneath it.

Charles. Besides, I imagine you put the water round the edge of the glass to prevent the air from rushing between it and the leather.

Father. You are right; for air being the lighter fluid could not ascend through the layer of water in order to descend into the receiver.—Could suction produce the effect in this experiment?

Charles. I think not; because the little receiver was not fixed till after what might be thought suction had ceased to act.

Father. Right; and to impress this fact

strongly on your mind, I will repeat the experiment. You observe that the air being taken from under both receivers, the large one must be fixed by the pressure of the atmosphere, and the smaller one must be loose, because there is no pressure on its outside to fasten it. But by admitting the air, the inner one becomes fixed by the very means that the outer one is loosened.

Emma. How will you get the small one away?

Father. As I cannot *raise* it, I must slide it over the hole in the brass plate; and now the air gets under it, there is not the smallest difficulty.

CONVERSATION XXVII.

Of the Pressure of the Air.

CHARLES. Although suction has nothing to do in the experiments which you made yesterday, yet I think I can show you an instance in which it has. This experiment, if such it may be called, I have made a hundred times. I fasten a string in the centre of a round piece of leather, and having thoroughly soaked it in water, I press it on a flat stone, and by pulling at the string the leather draws up the stone, although it be not more than two or three inches in diameter, and the stone weighs [illegible]nds. Surely this is suction.

Father. I should say so too, if I could not account for it by the pressure of the atmosphere. By pressing the wet leather on the stone you displace the air, then by pulling the string a vacuum is left at the centre, and the pressure of the air about the edges of the leather is so great, that it requires a greater power than the gravity of the stone to separate them.

I have seen you drink water from a spring by means of a hollow straw.

Emma. Yes, that is another instance of what we have been accustomed to call suction.

Father. But now you know, that in this operation you made a syringe with the straw and your lips, and by drawing in your breath you cause a vacuum in the hollow straw tube, and the pressure of the air on the water in the spring forces it up through the straw into the mouth.

Charles. I cannot, however, help thinking that this looks like suction, for the mo-

ment I cease the drawing in my breath, the water ceases to rise in my mouth,

Father. That is, when there is no longer a vacuum in the straw, the pressure within is just equal to that without, and consequently the water will rest at its natural level.

I will show you another striking instance of the effects of the air's pressure. This instrument (Plate v. Fig. 10.) is called the transferrer. The screw C fits on to the plate of the air-pump, and by means of the stop-cocks G and H, I can take away the air from both, or either of the receivers I, K, at pleasure.

Emma. Is there a channel then running from C through D A B, and thence passing to x, and y?

Father. There is. I will screw the whole on the air-pump, and turn the cock G, so that there is now no communication from C to the internal part of the receiver I. At present you observe that

both the receivers are perfectly free. By turning the handle of the pump a few times the air is taken away from the receiver K, and to prevent its re-entrance I turn the stop-cock *d*. Try if you can move it.

Charles. I cannot: but the other is loose.

Father. The pressure of the atmosphere is evidently the same on the two receivers; but with regard to the glass I, the pressure within is equal to that without, and the glass is free: in the other, the pressure from within is taken away, and the glass is fixed. In this stage of the experiment you are satisfied that there is a vacuum in the receiver K. By turning the cock G, I open a communication between the two receivers, and you hear the air that was in I rush through the channel A B into K, Now try to move the glasses.

Emma. They are both fixed: how is this?

Father. The air that was enclosed in the glass I is equally diffused between the two, consequently the internal pressure of neither is equal to the external, and therefore they are both fixed by the excess of the external pressure over the internal. In this case it could not be suction that fixed the glass I, for it was free long after what might have been thought suction had ceased to act.

Charles. What are these brass cups? (Plate v. Fig. 11.)

Father. They are called the hemispherical cups; I will bring the two, B, A, together, with a wet leather between them, and then screw them by D to the plate of the air-pump: and having exhausted the air from the inside, I turn the stop-cock E, take them from the pump, and screw on the handle F. See if you two can separate them.

Emma. We cannot stir them.

Father. If the diameter of these cups were four inches, the pressure to be over-

come would be equal to 180lb. I will now hang them up in the receiver (Plate v. Fig. 12.) and exhaust the air out of it, and you see they separate without the application of any force.

Charles. Now there is no pressure on the outside, and therefore the lower cup falls off by its own gravity.

Father. With this steel-yard (Plate vi. Fig. 13.) you may try very accurately to what weight the pressure of the atmosphere against the cups is equal.*

Emma. For when the weight w is carried far enough to overcome pressure of the cups, it lifts up the top one.

Father. I have exhausted the air of this receiver H, (Plate vi. Fig. 14.) consequently it is fixed down to the brass plate I; to the plate is joined a small tube with a stop-

* The principle of the steel-yard is explained, Vol. 1. of Mechanics, Conversation XV.

cock *x*; by placing the lower end of the tube in a bason of water, and turning the cock, the pressure of the atmosphere on the water in the bason forces it through the tube in the form of a fountain. This is called the fountain *in vacuo*.

To this little square bottle A (Plate VI. Fig. 15.) is cemented a screw valve, by which I can fix it on the plate of the air-pump, and exhaust its air: and you will see that when there is no power within to support the pressure of the atmosphere from without, it will be broken into a thousand pieces.

Charles. Why did you not use a round phial?

Father. Because one of that shape would have sustained the pressure like an arch.

Emma. Is that the reason why the glass receivers are able to bear such a weight without breaking?

Father. It is. If mercury be poured into a wooden cup C, made of willow,

which is a very porous kind of wood, (Plate VI. Fig. 16.) and the air taken from under it, the mercury will, by the weight of the external air, be forced through the pores of the wood, and descend like a shower of rain.

CONVERSATION XXVIII.

Of the Weight of Air.

EMMA. We have seen the surprising effects of the air's pressure, are there any means of obtaining the exact weight of air?

Father. If you do not require any very great nicety, the method is very simple.

This Florence flask (Plate VI. Fig. 17.) is fitted up with a screw, and a fine oiled silk valve at D. I will now screw the flask on the plate of the air-pump, and exhaust the air. You see, in its present exhausted state, it weighs 3 ounces and 5 grains.

Charles. Cannot the air get through the

Father. The silk, being varnished with a kind of oily substance, is impenetrable to air; and, being exhausted, the pressure upon the outside effectually prevents the entrance of the air by the edge of the silk; but if I lift it up by means of this sewing-needle, you will hear the air rush in.

Emma. Is that hissing noise occasioned by the re-entrance of the air?

Father. It is; and when that ceases, you may be sure the air within the bottle is of the same density as that without.

Charles. If I weigh it again, the difference between the weight now, and when you tried it before, is the weight of the quantity of air contained in the bottle;—it weighs very accurately 3 ounces 19¼ grains, consequently the air weighs 14¼ grains.

Father. And the flask holds a quart, wine-measure.

Emma. Does a quart of air always weigh 14¼ grains?

Father. The weight of the air is perpetually changing; therefore though a quart

of it weighs to-day $14\frac{1}{4}$ grains, the same quantity may, in a few hours, weigh $14\frac{1}{2}$ grains, or perhaps only 14 grains, or more or less. The air is much heavier this morning than it was at the same time yesterday.

Charles. How do you know that; did you weigh some yesterday?

Father. No: but the rising and falling of the quicksilver in the barometer, an instrument which I shall hereafter very particularly describe, are sure guides by which the real weight of the air is estimated; and it stands full three-tenths of an inch higher now than it did yesterday.

Emma. Will you explain how we may judge of the different weights of the air by the barometer?

Father. This subject might, perhaps, be better discussed when we come to treat explicitly on that instrument; but I will now answer your inquiry, although I should be in some danger of a repetition on a future day.

The mercury in a well-made barometer will always subside till the weight of the column be axactly equivalent to the weight of the external air upon the surface of the mercury in the bason, consequently the height of the mercury is a sure criterion by which that weight is to be estimated.—Suppose, for example, the barometer stands at 29½ inches, or, as it is usually expressed, at 29.5, and I find a quart of air at that time weighs 14½ grains. Here then is a standard by which I may ever after compare the gravity of the atmosphere. If to-morrow I find the quicksilver has fallen to 29.3, I shall know the air is not so heavy as it was; because, in this case, a column of quicksilver, 29.3 inches, balances the whole weight; whereas it required before, a column equal to 29.5. If, on the contrary, when I look again, the mercury has risen to 30.6, as it really stands at this hour, Sept. 29, 1805, I am sure the atmosphere is considerably heavier than it was before, and that a quart of it will weigh much more than 14½ grains.

Charles. You intimated that in weighing air the flask could not be depended upon if great nicety were required; what is the reason of that?

Father. I told you, when explaining the operations of the air-pump, that it was impossible to obtain, by means of that instrument, a perfect vacuum. The want of accuracy in the flask experiment depends on the small quantity of air that is left in the vessel after the exhaustion is carried as far as it will go: this, however, if the pump be good, will, after 12 turns of the handle, be less than the 4000th part of the whole quantity.

Emma. How do you know this?

Father. You seem unwilling to take any thing upon my word; and in subjects of this kind you do right, never to rest satisfied without a reason for what is asserted.

I suppose, then, each of the barrels of the air-pump is equal in capacity to the flask; that is, each will contain a quart; then it is [illegible]hat, by turning the handle of the

pump, I exhaust all the air of one barrel, and the air in the flask becomes at the same time equally diffused between the barrel and flask; that is, the quart is now divided into two equal parts, one of which is in the flask, and the other in the barrel. By the same reason, at the next turn of the handle, the pint in the flask will be reduced to half a pint; and so it will go on decreasing, by taking away, at every turn, one half of the quantity that was left in by the last turn.

Charles. Do you mean then, that after the first turn of the handle, the air in the bottle is twice as rare as it was at first; and after the second, third, and fourth turns, it is four times, eight times, and sixteen times as rare as it was when you began?

Father. That is what I meant; carry on your multiplication, and you will find that after the twelfth turn it is 4096 times more rare than it was at first.

Emma. I now understand that, though absolute exactness be not attainable, yet, in weighing this quart of air, the error is only

equal to the 4096th part of the whole: which quantity may, in reasoning on the subject, be overlooked.

Father. I will exhaust the flask again of its air, and putting the neck of it under water, I will lift up the silk valve, and fill it with water. Now dry the outside very thoroughly, and weigh it.

Charles. It weighs 27 ounces.

Father. Subtract the weight of the flask, and reduce the remainder into grains, and divide by $14\frac{1}{4}$, and you will obtain the specific gravity of water compared with that of the air.

Charles. I have done it, and the water is something more than 800 times heavier than air.

Father. Since, then, the specific gravity of water is always put at 1, that of air must be as $\frac{1}{800}$th, at least according to this calculation; but following the more accurate experiments of Mr. Cavendish and others, whose authority may be safely appealed to, the specific gravity of air is 800 times less

an that of water, when the barometer ands as high as 30 inches.

Can you tell me what the air in this om weighs? the length of the room is 25 et, the height $10\frac{1}{2}$, and the width $12\frac{1}{2}$?

Emma. I multiply these three numbers gether, and the answer is 3281.25; or the om contains a little more than 3281 cubic et: now a cubic foot of water weighs 1000 unces, therefore the weight of the room-ull of water would be 3,281,000 ounces; but air being 800 times lighter than water, the air in the room will weigh $3,281,000 \div 800 = 4101$ ounces $=$ 256lb. 5oz. It seems however surprising that the air, which is invisible, should weigh so much.

CONVERSATION XXIX.

Of the Elasticity of Air.

FATHER. I have told you that air is an elastic fluid. Now it is the nature of all elastic bodies to yield to pressure, and to endeavour to regain their former figure as soon as the pressure is taken off. In projecting an arrow from your bow, you exert your strength to bring the two ends of the bow nearer together, but the moment you let go the string, it recovers its former shape: the power by which this is effected is called *elasticity*.

Emma. Is it not by this power that India-rubber, after it has been stretched, recovers its usual size and form?

Father. It is: and almost every thing that you make use of possesses this property in a greater or less degree: balls: marbles, the chords of musical instruments, are all elastic.

Charles. I understand how all these things are elastic: but do not see in what manner you can prove the elasticity of the air.*

Father. Here is a bladder, which we will fill with air, and tie up its mouth, to prevent its escaping again. If you now press upon it with your hand, its figure will be changed; but the moment the pressure is removed, it recovers its round shape.

Emma. And if I throw it on the ground or against any other obstacle it rebounds, like a ball or marble.

Father. You are satisfied also, I presume, that it is the air which is the cause of it, and not the bladder that contains it.

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* See Vol. I. Of Mechanics, Conversation XII.

Let us have recourse to the air-pump to exhibit some of the more striking effects of the air's elasticity. I will let a part of the air out of the bladder, and tie up its mouth again. The pressure of the external air renders it flaccid and you may make what impression you please upon it, without its endeavouring to re-assume its former figure.

Emma. What proof is there that this is owing to the external pressure of the air.

Father. Such as will satisfy you both, I am sure. Place it under the receiver of the air-pump, exhaust the air, and see the consequences.

Charles. It begins to swell out;—and now it is as large as when it was blown out full of air.

Father. The outward pressure being in part removed, the particles of air, by their elasticity, distend, and fill up the bladder; and if it were much larger, and the exhaustion were carried farther, the same

small quantity of air would fill it completely. I will now let the air in again.

Emma. This exhibits a very striking proof of the power and pressure of the external air, for the bladder is as flaccid as it was before.

Father. I put the same bladder into this square box without any alteration, and place upon it a moveable lid, upon which I put this weight. By bringing the whole under a receiver, and exhausting the external air, the elasticity of that in the bladder will lift up the lid and weight together.

Charles. If you pump much more, the weight will fall against the side of the glass.

Father. I do not mean to risk that:—it is enough that you see a few grains, not half a dozen of air, will, by their elasticity, raise and sustain a weight of several pounds.

Take this glass bubble: (Plate v. Fig. 8.) the bore of the tube is too small for the water to run out; but if I place it under the receiver of the air-pump, and take

away the external air, the little quantity of air which is at the top of the glass, will, by its elastic force, expand itself, and drive out all the water.

Emma. This experiment shows, that a very small quantity of air is capable of filling a large space, provided the external pressure is taken off.

Father. Certainly: I will take off the bladder from this glass. (See Plate III. Fig. 19.) The little images all swim at the top, the air contained in them rendering them rather lighter than the water. Tie little leaden weights to their feet, these pull them down to the bottom of the vessel: I now place the glass under the receiver of the air-pump, and by exhausting the air from the vessel, that which is within the images, by its elasticity, expands itself, forces out more water, and you see they are ascending to the top, dragging the weights after them. I will let in the air, and the pressure forces the water into the images again, and they descend.

Here is an apple very much shrivelled, which, when placed under the receiver, and the external air taken away, will appear as plump as if it were newly gathered from the tree.

Emma. Indeed it now looks so inviting, that I am ready to wish it was my own.

Father. Before, however, you can get it, all its beauty will fade. I will admit the air again.

Charles. It is as shrivelled as ever. Do apples contain air?

Father. Yes, a great deal; and so, in fact, do almost all bodies that are specifically lighter than water, as well as many that are not so. It was the elastic power of the air within the apple, that forced out all the shrivelled parts when the external pressure was taken away.

Here is a small glass of warm ale, from which I am going to take away the air.

Emma. It seems to boil now you exhaust the air from the receiver.

Father. The bubbling is caused by the air endeavouring to escape from the liquor. Let the air in again, and then taste the beer.

Charles. It is flat and dead.

Father. You see of what importance air is to give to all our liquors their pleasant and brisk flavour, for the same will happen to wine and all other fermented fluids.

Emma. How is it that the air, when it was re-admitted, did not penetrate the ale again?

Father. It could not insinuate itself into the pores of the beer, because it is the lighter body, and therefore will not descend through the heavier. Besides, it does not follow that it is the same sort of air, which I admitted into the receiver, that was taken from the ale.

Emma. Are there more kinds of air than one?

Father. Yes, very many; as we shall you in our Conversations on Che-

mistry.* That which I took from the beer, and which gives it the brisk and lively taste, is called fixed air, or carbonic acid gas, of which there is, in general, but a very small quantity in the atmosphere.

"The elasticity, or spring of air, contained in our flesh, was clearly shown by the experiment, when I pumped the air from under your hand.

Charles. Was that the cause of its swelling downward?

Father. It was: and it will account for the pain you felt, which was greater, and of a very different kind, than what you would have experienced by a dead weight being laid on the back of your hand, equal to the pressure of the air.

Cupping is an operation performed on this principle: the operator tells you he draws up the flesh; but if he were to speak

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* See Dialogues in Chemistry, Vol. I.

correctly, he would say, he took away the external air from off the part of the body, and then the elastic force of the air within extends, and swells out the flesh ready for his lancets.

Emma. When I saw you cupped, he did not use an air-pump, but little glasses, to raise the flesh.

Father. Glasses closed at top are now generally made use of, in which the operator holds the flame of a lamp: by the heat of this the elasticity of the air in the glass is increased, and thereby a great part of it driven out. In this state the glass is put on the part to be cupped, and as the inward air cools, it contracts, and the glass adheres to the flesh by the difference of the pressures of the internal and external air.

By some persons, however, the syringe is considered as the most effectual method of performing the operation, because by flame the air cannot be rarified more than

one half; whereas by the syringe a few strokes will nearly exhaust it.

Here is another little square bottle like that before mentioned, (Plate VI. Fig. 15.) only that it is full of air, and the mouth sealed so closely that none of it can escape. I enclose it within the wire cage B, and in this state bring them under the receiver, and exhaust the external air.

Charles. With what a loud report it has burst!

Father. You can easily conceive now in what manner this invisible fluid endeavours continually, by its elastic force, to dilate itself.

Emma. Why did you place the wire cage over the bottle?

Father. To prevent the pieces of the bottle from breaking the receiver, an accident that would be liable to happen without this precaution.

Take a new laid egg and make a small hole in the little end of it, then, with that end downwards, place it in an ale-glass un-

der the receiver, and exhaust the air; the whole contents of the egg will be forced out into the glass, by the elastic spring of the small bubble of air which is always to be found in the large end of a new-laid egg.

CONVERSATION XXX.

The Compression of the Air.

FATHER. I have already alluded to the compressibility of air, which it is proper to describe here, it being a consequence of its elasticity: for whatever is elastic, is capable of being forced into a smaller space. In this respect air differs very materially from other fluids.

Charles. You told us, that water was compressible in a very small degree.

Father. I did so; but the compression which can be effected with the greatest power, is so very small, that without the greatest attention and nicety in conducting

the experiments, it would never have been discovered. Air, however, is capable of being compressed into a very small space compared with what it naturally possesses.

Emma. The experiment you made, by plunging an ale-glass with its mouth downwards, clearly proved that the air which it contained was capable of being reduced into a smaller space.

Father. This bended tube A B C (Plate VI. Fig. 18.) is closed at A and open at C. It is in the common state, full of air. I first pour into it a little quicksilver just sufficient to cover the bottom *a b*: now the air in each leg is of the same density, and, as that contained in A B cannot escape, because the lighter fluid will be always uppermost, when I pour more quicksilver in at C, its weight will condense the air in the leg A B; for the air which filled the whole length of the leg is, by the weight of the quicksilver in C B, pressed into the smallest space A *x*, which space will be diminished as the weight is increased: so that by increasing the length

of the column of mercury in C B, the air in the other leg will be more and more condensed. Hence we learn that the elastic spring of air is always, and under all circumstances, equal to the force which compresses it.

Charles. How is that proved?

Father. If the spring with which the air endeavours to expand itself when it is compressed, were less than the compressing force, it must yield still farther to that force; that is, if the spring of the air in A x were less than equal to the weight of the mercury in the other leg, it would be forced into a yet smaller space; but if the spring were greater than the weight pressing upon it, it would not have yielded so much; for you are well aware that action and re-action are equal, and act in opposite directions.

You can now easily understand why the lower regions of the atmosphere are more dense than those higher.

Emma. Because they are pressed upon by all the air that is above them, and therefore condensed into a smaller space.

Father. Consequently the air grows gradually thinner, till at a considerable height it may be conceived to degenerate to nothing. The different densities of the air may be illustrated by conceiving twenty or thirty equal packs of wool placed one upon another: the lowest will be forced into a less space, that is, its parts will be brought nearer together, and it will be more dense, than the next; and that will be more dense than the third from the bottom, and so on till you come to the uppermost, which sustains no other pressure than that occasioned by the weight of the incumbent air.

Let us now see the effects of condensed air, by means of an artificial fountain. This vessel is made of strong copper (Plate VI. Fig. 19.), and about half full of water. With a syringe that screws to the pipe A B I force a considerable quantity of air into the vessel, so that it is very much condensed. By turning the stop-cock B while I take off the syringe, no water can escape: and instead of the syringe I put on a jet, or

very small tube, after which the stop-cock is turned, and the pressure of the condensed air forces the water through the tube to a very great height.

Charles. Do you know how high it ascends?

Father. Not exactly: but as the natural pressure of the air will raise water 33 feet, so if by condensation its pressure be tripled, it will rise 66 feet.

Emma. Why tripled? Ought it not rise to this height by a double pressure?

Father. You forget that there is the common pressure always acting against, and preventing the ascent of the water, therefore besides a force within to balance that without, there must be a double pressure.

Charles. You describe a syringe to be like a common water-squirt, how are you able by an instrument of this kind to force in so great a quantity of air? will it not return by the same way it is forced in?

Father. The only difference between a

condensing syringe and a squirt is, that, in the former, there is a valve that opens downwards, by which air may be forced through it, but the instant that the downward pressure ceases, the valve, by means of a strong spring, shuts of itself, so that none can return.

Emma. Will not air escape back, during the time you are forcing in more of the external air?

Father. That would be the case if the syringe pipe went no lower than that part of the vessel which contains the air, but it reaches to a considerable depth in the water, and as it cannot find its way back up the pipe, it must ascend through the water, and cause that pressure upon it which has been described.

Charles. To what extent can air be compressed?

Father. If the apparatus be strong enough, and a sufficient power applied, it may be condensed several thousand times; that is, a vessel which will contain a gallon of air in its

natural state may be made to contain several thousand gallons.

By means of a fountain of this kind, young people, like yourselves, may receive much entertainment with only a few additional jets, which are made to screw on and off. One kind is so formed that it will throw up and sustain on the stream a little cork ball, scattering the water all round. Another is made in the form of a globe, pierced with a great number of holes, all tending to the centre, exhibiting a very pleasing sphere of water. One is contrived to show, in a neat manner, the composition and resolution of forces explained in our first volume.* Some will form cascades; and by others you may, when the sun shines at a certain height in the heavens, exhibit artificial rainbows.†

We will now force in a fresh supply of air, and try some of these jets.

* See Vol. I. Of Mechanics. Conversation XIII.

† This phenomenon is described and explained in Conversation XVIII.

Emma. I observed in the upright jets, that the height to which the water was thrown was continually diminishing.

Father. The reason is this; that in proportion as the quantity of water in the fountain is lessened, the air has more room to expand, the compression is diminished, and consequently the pressure becomes less, till at length it is no greater within than it is without, and then the fountain ceases altogether.

CONVERSATION XXXI.

Miscellaneous Experiments on the Air-Pump.

FATHER. I shall, to-day, exhibit a few experiments, without any regard to the particular subjects under which they might be arranged.

In this jar of water I plunge some pieces of iron, zinc, stone, &c. and you will see that when I exhaust the external air, by bringing the jar under the receiver of the air-pump, the elastic spring of air contained in the pores of these solid substances will force them out in a multitude of globules, and exhibit a very pleasing spectacle, like the pearly dew-drops on

blades of grass; but when I admit the air, they suddenly disappear.

Emma. This proves what you told us a day or two ago, that substances in general contain a great deal of air.

Father. Instead of bodies of this kind, I will plunge in some vegetable substances, a piece or two of the stem of beet-root, angelica, &c, and now observe, when I have exhausted the receiver, what a quantity of air is forced out of the little vessels of these plants by means of its elasticity.

Charles. From this experiment we may conclude that air makes no small part of all vegetable substances.

Father. To this piece of cork, which of itself would swim on the surface of water, I have tied some lead, just enough to make it sink. But by taking off the external pressure, the cork will bring the lead up to the surface.

Emma. Is that because when the pressure is taken off, the substance of the cork

expands, and becomes specifically lighter than it was before?

Father. It is: this experiment is varied by using a bladder, in which is tied up a very small quantity of air, and sunk in water; for when the external pressure is removed, the spring of air within the bladder will expand it, make it specifically lighter than water, and bring it to the surface.

The next experiment shows that the ascent of smoke and vapours depends on the air. I will blow out this candle, and put it under the receiver; the smoke now rises to the top, but as soon as the air is exhausted to a certain degree, the smoke descends, like all other heavy bodies.

Charles. Do smoke and vapours rise because they are lighter than the surrounding air?

Father. That is the reason: sometimes you see smoke from a chimney rise very perpendicularly in a long column; the air

then is very heavy: at other times you may see it descend, which is a proof that the density of the atmosphere is very much diminished, and is, in fact, less than that of the smoke. And at all times the smoke can ascend no higher than where it meets with air of a density equal to itself, and there it will spread about like a cloud.

This figure (Plate VI. Fig. 20.) is usually called the lungs-glass: a bladder is tied close about the little pipe *a*, which is screwed into the bottle A. I introduce it under the receiver A, B, and begin to exhaust the air of the receiver, and that in the bladder communicating with it, will also be withdrawn; the elastic force of the air in the bottle A will now press the bladder to the shrivelled state represented in the figure: I will admit the air, which expands the bladder; and thus by alternately exhausting and re-admitting the air, I show the action of the lungs in breathing. But perhaps the following experiment will give a better idea of the subject (Plate VI. Figs.

21 and 22.) A represents the lungs, B the windpipe leading to them, which is closely fixed in the neck of the bottle, from which the air cannot escape: D is a bladder tied to the bottom, and in its distended state (Fig. 21.) will, with the internal cavity of the bottle, represent the cavity of the body which surrounds the lungs at the moment you have taken in breath: I force up D (as in Fig. 22.) and now the bladder is shrivelled by the pressure of the external air in the bottle, and represents the lungs just at the moment of expiration.

Emma. Does Fig. 21. show the state of the lungs after I have drawn in my breath, and Fig. 22. when I have thrown it out forcibly?

Father. That is what the figures are intended to represent, and they are well adapted to show the elevation and compression of the lungs, although I do not mean to assert, that the action of the lungs in breathing depends upon air in the same manner as that in the bladder does upon

the air which is contained in the cavity of the bottle.

I have exactly balanced on this scale-beam a piece of lead and a piece of cork: in this state I will introduce them under the receiver, and exhaust the air.

Charles. The cork now seems to be heavier than the lead.

Father. In air each body *lost* a weight proportional to its *bulk*, but when the air is taken away, the weight lost will be restored: but as the lead lost least, it will now retrieve the least, consequently the cork will preponderate with the difference of the weights restored by taking away the air.

Thus you see that *in vacuo, a pound of cork, or feathers,* would be heavier *than a pound of lead.*

CONVERSATION XXXII.

Of the Air-Gun, and Sound.

FATHER. The air-gun is an instrument, the effects of which depend on the elasticity and compression of air.

Emma. Is it used for the same purposes as common guns?

Father. Air-guns will answer all the purposes of a musket or fowling-piece: bullets discharged from them will kill animals at the distance of 50 or 60 yards. They make no report, and on account of the great mischief they are capable of doing, without much chance of discovery, they are deemed

illegal, and are, or ought to be, found no where but among the apparatus of the experimental philosopher.

Charles. Can you show us the construction of an air-gun?

Father. It was formerly a very complex machine, but now the construction of air-guns is very simple; this (Plate VI. Fig. 23.) is one of the most approved.

Emma. In appearance it is very much like a common musket, with the addition of a round ball c.

Father. That ball is hollow, and contains the condensed air, into which it is forced by means of a syringe, and then screwed to the barrel of the gun.

Charles. Is there fixed to the ball a valve opening inwards?

Father. There is: and when the leaden bullet is rammed down, the trigger is pulled back, which forces down the hook *b* upon the pin connected with the valve, and liberates a portion of the condensed air; this

rushing through a hole in the lock into the barrel, will impel the bullet to a great distance.

Emma. Does not all the air escape at once?

Father. No: if the gun be well made, the copper ball will contain enough for 15 or 20 separate charges: so that one of these is capable of doing much more execution in a given time than a common fowling-piece.

Charles. Does not the strength of the charges diminish each time?

Father. Certainly; because the condensation becomes less upon the loss of every portion of air; so that after a few discharges the bullet will be projected only a short distance. To remedy this inconvenience, you might carry a square ball or two ready filled with condensed air in your pocket, to screw on when the other was nearly exhausted. Formerly this kind of instrument was attached to gentlemen's walking sticks.

Charles. I should like to have one of them.

Father. I dare say you would: but you must not be trusted with instruments capable of doing much mischief, till it is quite certain that your reason will restrain you from actions that might annoy other persons.

A still more formidable instrument is called the magazine wind-gun. In *this* there is a magazine of bullets as well as another of air, and when it is properly charged, the bullets may be projected one after another as fast as the gun can be cocked, and the pan opened. The syringe in these is fixed to the but of the gun, by which it is easily charged, and may be kept in that state for a great while.

Emma. Does air never lose its elastic power?

Father. It would be too much to assert that it never will: but experiments have been tried upon different portions of it, which have been found as elastic as ever af-

ter the lapse of many months, and even years.

Charles. What is this bell for?

Father. I took it out to show you that air is the medium by which, in general, sound is communicated. I will place it under the receiver of the air-pump, and exhaust the air. Now observe the clapper of the bell while I shake the apparatus.

Emma. I see clearly that the clapper strikes the side of the bell, but I do not hear the least noise.

Father. Turn the cock and admit the air; now you hear the sound plain enough: —and if I use the syringe and a different kind of glass, so as to condense the air, the sound will be very much increased. Dr. Desaguliers says, that in air that is twice as dense as common air, he could hear the sound of a bell at double the distance.

Charles. Is it on account of the different densities of the atmosphere, that we hear St. Paul's clock so much plainer at one time than another?

Father. Undoubtedly the different degrees of density in the atmosphere will occasion some difference, but the principal cause depends on the quarter from which the wind blows, for as the direction of that is towards or opposite to our house, we hear the clock better or worse.

Emma. Does it not require great strength to condense air?

Father. That depends much on the size of the piston belonging to the syringe; for the force required increases in proportion to the square of the diameter of the piston.

Suppose the area of the base of the piston is one inch, and you have already forced so much air into the vessel that its density is double that of common air, the resistance opposed to you will be equal to 15 pounds; but if you would have it 10 times as dense, the resistance will be equal to 150 pounds.

Charles. That would be more than I could manage.

Father. Well, then, you must take a syringe, the area of whose piston is only

half an inch; and in that case the resistance would be equal to only the fourth part of 150 pounds, because the square of $\frac{1}{2}$ is equal to $\frac{1}{4}$.*

Emma. You said that the air was *generally* the medium by which sound is conveyed to our ears; is it not always so?

Father. Air is always a good conductor of sound, but water is a still better. Two stones being struck together under water, the sound may be heard at a greater distance by an ear placed under water in the same river, than it can through the air. In calm weather a whisper may be heard across the Thames.

The slightest scratch of a pin at one end of a long piece of timber, may be heard by an ear applied near the other end, though it could not be heard at half the distance through the air.

* The square of any number being the number multiplied into itself, $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$.

The earth is not a bad conductor of sound: it is said, that by applying the ear to the ground, the trampling of horses may be heard much sooner than it could through the medium of the air. Recourse has sometimes been had to this mode of learning the approach of a hostile army.

Take a long strip of flannel, and in the middle tie a common poker, which answers as well as any thing, leaving the ends at liberty; these ends must be rolled round the end of the first finger of each hand, and then stopping the ears with the ends of these fingers, strike the poker, thus suspended, against any body, as the edge of a steel fender; the depth of the tone which the stroke will return is amazing; that made by the largest church-bell is not to be compared with it—Thus it appears that flannel is an excellent conductor of sound.

CONVERSATION XXXIII.

Of Sound.

FATHER. We shall devote this conversation to the consideration of some curious circumstances relating to sound; which, as depending upon the air, will come very properly under Pneumatics.

Charles. You showed us yesterday that the stroke, made by the clapper of a bell was not audible, when it was under an exhausted receiver; is the air the cause of sound?

Father. Certainly in many cases it is: of this kind is thunder, the most awful sound in nature:

——The air is vehicle of sound;
Remove but the elastic pulse of air,
And the same ear, which now delighted feels
The nice distinction of the finest notes,
Would not discern the thunder from a breeze.

EUDOSIA.

Emma. Is thunder produced by the air?

Father. Thunder is generally supposed to be produced by the concussion or striking together of two bodies of air; for lightning, darting through the air, causes, by its great velocity, a vacuum, and the separated bodies of air rushing together produce the noise we call thunder. The same effect, only in miniature, is produced by the inflammation of gun-powder.

Charles. Can the report of a large cannon be called a miniature imitation? I remember being once in a room at the distance of but a few paces from the Tower guns when they fired, and the noise was

infinitely worse than any thunder that I ever heard.

Father. This was because you were near to them: gunpowder, so tremendous as it is in air, when inflamed in a vacuum makes no more sound than the bell in like circumstances.

Mr. Cotes mentions a very curious experiment, which was contrived to show that sound cannot penetrate through a vacuum. A strong receiver filled with common atmospheric air, in which a bell was suspended, was screwed down to a brass plate so tight that no air could escape, and this was included in a much larger receiver. When the air between the two receivers was exhausted, the sound of the bell could not be heard.

Emma. Could it be heard before the air was taken away?

Father. Yes: and also the moment it was re-admitted.

Charles. What is the reason that some bodies sound so much better than others?

Bell-metal is more musical than copper or brass, and these sound much better than many other substances.

Father. All sonorous bodies are elastic, the parts of which by percussion are made to vibrate: and as long as the vibrations continue, corresponding vibrations are communicated to the air, and these produce sound. Musical chords and bells are instances that will illustrate this.

Emma. The vibrations of the bell are not visible; and musical chords will vibrate after the sound has vanished.

Father. If light particles of dust be on the outside of a bell when it is struck, you will, by their motion, have no doubt but that the particles of the metal move too, though not sufficiently to be visible to the naked eye: and though the motion of a musical string continues after the sound ceases to be heard, yet it does not follow that sound is not still produced, but only that it is not sufficiently strong to produce ation in the ear. You see in a dark

night the flash of a gun, but, being at a considerable distance from it, you hear no report. If, however, you knew that the light was occasioned by the inflammation of gun-powder, in a musket or pistol, you would conclude that it was attended with sound, though it was not sufficiently strong to reach the place where you are.

Charles. Is it known how far sound can be heard?

Father. We are assured upon good authority, than the unassisted human voice has been heard at the distance of ten or twelve miles; namely, from New to Old Gibraltar. And in the famous sea-fight between the English and Dutch in 1672, the sound of cannon was heard at the distance of two hundred miles from the place of action.—In both these cases the sound passed over water; and it is well known that sound may be always conveyed much farther along a smooth than an uneven surface.

Experiments have been instituted to as-

certain how much water, as a conductor of sound, was better than land; and a person was heard to read very distinctly at the distance of 140 feet on the Thames, and on land he could not be heard farther than 76 feet.

Emma. Might not there be interruptions in the latter case?

Father. No noise whatever intervened by land, but on the Thames there was some occasioned by the flowing of the water.

Charles. As we were walking last summer towards Hampstead, we saw a party of soldiers firing at a mark near Chalk Farm, and you desired Emma and me to take notice, as we approached the spot, how much sooner the report was heard after we saw the flash than it was when we first got into the fields.

Father. My intention was, that you should know from actual experiment that sound is not conveyed instantaneously, but

takes a certain time to travel over a given space.

When you stood close to the place, did you not observe the smoke and hear the report at the same instant?

Emma. Yes, we did.

Father. Then you are satisfied that the light of the flash, and the report, are always produced together. The former comes to the eye with the velocity of light, the latter reaches the ear with the velocity with which sound travels: if then light travels faster than sound, you will at any considerable distance from a gun that is fired, see the flash before you hear the report. Do you know with what velocity light travels.

Charles. At the rate of 12 million of miles in a minute*.

Father. With regard then to several hundred yards, or even a few miles, the motion of light may be considered as in-

* See Vol. I. Of Astronomy. Conversation XLV

stantaneous; that is, there would be no assignable difference of time to two observers, one of whom should stand at the breech of the gun, and the other at the distance of six, or eight, or ten miles from it.

Emma. This I understand, because 10 miles is as nothing when compared with 12 millions.

Father. Now sound travels only at the rate of about 13 miles in a minute; therefore, as time is easily divisible into seconds, the progressive motion of sound is readily marked by means of a stop-watch: consequently, if persons situated, some close to a gun when it is discharged, others at a quarter of a mile from it, and others at half a mile, and so on; they will all see the flash or smoke at the same instant, but the report will reach them at different times.

Charles. Is it certain that sounds of all kinds travel at this rate?

Father. A great variety of experiments have been made on the subject, and it seems now generally agreed that sound travels

with a velocity that is equal to 1142 feet in a second of time.

Emma. Then with a stop-watch you could have told how far we were from the firing when we first saw it.

Father. Most easily; for I should have counted the number of seconds that elapsed between the flash and the report, and then have multiplied 1142 by the number, and I should have had the exact distance in feet between us and the gun.

Charles. Has this knowledge been applied to any practical purpose?

Father. It has frequently been used at sea, by night, to know the distance of a ship that has fired her watch-guns. Suppose you were in a vessel, and saw the flash of a gun, and between that and the report 24 seconds elapsed, what would be the distance of one vessel from another?

Emma. I should multiply 1142 by 24, and then bring the product into miles, which in this instance is equal to something more than five miles.

Father. The mischief occasioned by lightning is supposed to depend much on the distance at which the storm is from the spot from whence it is seen.

By counting the number of seconds elapsed between the flash of lightning and the clap of thunder, you may ascertain how far distant you are from the storm.

Charles. I should like to have a stop-watch, to be able to calculate this for myself.

Father. As it will, probably, be some time before you become possessed of this expensive instrument, I will tell you of something which you have always about you, and which will answer the purpose.

Emma. What is that, papa?

Father. The pulse at your wrist, which, in healthy people, generally beats about 75 times in a minute:* in the same space of time sound flies 13 miles: therefore, in one pulsation sound passes over 13 miles

* In children the pulse is more rapid.

divided by 75, that is about 915 feet, or the $\frac{1}{8}$th part of a mile, consequently in six pulsations it will pass over a mile.

Emma. If I see a flash of lightning, and between that and the thunder I count at my wrist 36 or 60 pulsations, I say the distance in one case is equal to six miles, in the other ten.

Father. You are right: and this method will, for the present be sufficiently accurate for all your purposes.

CONVERSATION XXXIV.

Of the Speaking-Trumpet.

CHARLES. I have been thinking about the nature of sound, and am ready to ask what it is; I can conceive of particles of light issuing from the sun, or other luminous bodies, but I know not what sound is.

Father. It would be but of little use to give you a definition of sound, but I will endeavour to illustrate the subject. Sound is not a body like light, but it depends on the concussion or striking together of other bodies that are elastic, which being put into a tremulous motion, excite a wave in the surrounding air.

Emma. Is it such a wave as we see in the pond when it is ruffled by the wind?

Father. Rather such a one as is produced by throwing a pebble into still water.

Charles. I have often observed this; the surface of the water forms itself into circular waves.

Father. It is probable that the tremulous motion of the parts of a sonorous body communicate undulations in the air in a similar manner. Two obvious circumstances must strike every observer with regard to the undulations in water. (1.) The waves, the farther they proceed from the striking body, becomes less and less, till, if the water be of a sufficient magnitude, they become invisible, and die away. The same thing takes place with regard to sound; the farther a person is from the sounding body, the less plain it is heard, till at length the distance is too great for it to be audible; and (2.) the waves on the water are not propagated instantaneously, but are formed one after another in a given space of time. This,

from what we have already shown, appears to be the manner in which sound is propagated.

Emma. Is sound the effect which is produced on the ear by the undulations of the air?

Father. It is: and according as these waves are stronger or weaker, the impression, and consequently the sensation, is greater or less. If sound be impeded in its progress by a body that has a hole in it, the waves pass through the hole, and then diverge on the other side as from a centre. Upon this principle the *speaking-trumpet* is constructed.

Charles. What is that sir?

Father. It is a long tube, used for the purpose of making the voice heard at a considerable distance:—the length of the tube is from six to 12 or 15 feet, it is straight throughout, having at one end a large aperture, and the other terminates in a proper shape and size to receive the lips of the speaker.

Emma. Arè these instruments much in use?

Father. It is believed that they were more used formerly than now: they are certainly of great antiquity; Alexander the Great made use of such a contrivance to communicate his orders to the army; by means of which it is asserted he could make himself perfectly understood at the distance of 10 or 12 miles. Stentor is celebrated by Homer as one who could call louder than fifty men:

> Heaven's empress mingles with the mortal crowd,
> And shouts, in STENTOR's sounding voice aloud:
> Stentor the strong, endued with *brazen lungs*,
> Whose throat surpass'd the force of fifty tongues.
>
> POPE's HOMER, B. V. l. 976.

From Stentor the speaking-trumpet has been called the stentorophonic tube.

Charles. Perhaps Stentor was employed in the army for the purpose of communica-

ting orders of the general, and he might make use of a trumpet for the purpose, and that is what is meant by brazen lungs.

Father. That is not an improbable conjecture. Well, besides speaking-trumpets, there are others contrived for assisting the hearing of deaf persons, which differ but little from the speaking-trumpet.

If A and B (Plate VI. Fig. 24.) represents two trumpets, placed in an exact line at the distance of 40 feet or more from one another, the smallest whisper at *a* would be heard distinctly at *b*; so that by a contrivance to conceal the trumpets, many of those speaking figures are constructed which are frequently exhibited in the metropolis and other large towns.

Emma. I see how it may be done; there must be two sets of trumpets, the one connected with the ear of the image into which the spectator whispers, and which conveys the sound to a person in another room, who

by tubes connected with the mouth of the image returns the answer.*

Charles. How are the lips set in motion.

Father. Very easily, by means of a string or wire passing under the floor up the body of the image.

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* Dr. Young, in his excellent Lectures on Natural Philosophy, says that the exhibition, of the invisible girl is performed by conveying the sound through pipes, artfully concealed, and opening opposite the mouth of the trumpet, from which it seems to proceed. Vol. I. p. 376.

CONVERSATION XXXV.

Of the Echo.

FATHER. Let us turn our attention to another curious subject relating to sound, and which depends on the air; I mean the echo.

Emma. I have often been delighted to hear my own words repeated, and I once asked Charles how it happened that if I stood in a particular spot in the garden, and shouted loud, my words were distinctly repeated; whereas if I moved a few yards nearer to the wall I had no answer? He told me that he knew nothing

more than this, that in a part of Ovid's Metamorphosis, ECHO is represented as having been a nymph of the woods, but that pining away in love, her voice was all that was left of her.

Charles. I did; and you shall hear a translation of the whole passage:

So wond'rous are the effects of restless pain,
That nothing but her voice and bones remain,
Nay, e'en the very bones at last are gone,
And metamorphos'd to a thoughtless stone;
Yet still the voice does in the wood survive;
The forms departed, but the sound's alive.

Emma. But these lines say nothing of echo being a nymph.

Charles. Well, then, here are others applied immediately to echo:

A nymph she was, though only now a *sound*,
Yet of her tongue no other use was found,
Than now she has; which never could be more
Than to repeat what she had heard before.

Father. I doubt this will give your sister but little satisfaction respecting the cause of the echo which she has often heard, and which she may still hear in the garden.

Emma. No, I cannot conceive why a nymph of the woods should take up her residence in our garden, and the more so as I never saw her.

Father. If she is a mere sound, you cannot see her: I will endeavour to explain the subject.—When you throw a pebble into a small pool of water, what happens to the waves when they reach the margin?

Charles. They are thrown back again.

Father. The same happens with regard to the undulations in the air, which are the cause of sound. They strike against any surface fitted for the purpose, as the side of a house, a brick wall, a hill, or even against trees, and are reflected or beat back again: this is the cause of an echo.

Emma. I wonder then that we do not hear echo's more frequently.

Father. There must be several concurring circumstances before an echo can be produced. For an echo to be heard, the ear must be in the *line of reflection.*

Charles. I do not know what you mean by the line of reflection.

Father. I cannot always avoid using terms that have not been previously explained. This is an instance. I will, however, explain what is meant by the line of incidence, and the line of reflection. When you come to Optics, these subjects will be made very familiar to you. You can play at marbles?

Charles. Yes, and so can Emma.

Father. It is not a very common amusement for girls; however, as it happens, I shall find my advantage in it, as she will the more readily enter into my explanation.

Suppose you were to shoot a marble against the wainscot, what would happen?

Charles. That depends on the direction in which I shoot it: if I stand directly opposite to the wainscot, the marble will, if I shoot it strong enough, return to my hand.

Father. The line which the marble describes in going to the wall, is called the *line of incidence*, and that which it makes in returning *is the line of reflection.*

Emma. But they are both the same.

Father. In this particular instance they are so: but suppose you shoot obliquely or sideways against the board, will the marble return to the hand?

Charles. O no! it will fly off sideways in a contrary direction.

Father. There the line it describes *before the stroke*, or the line of incidence, is different from that of reflection, which it makes *after the stroke.* I will give you another instance: if you stand before the looking-glass you see yourself, because

the rays of light flow from you, and are reflected back again in the same line. But let Emma stand on one side of the room, and you on the other:—you both see the glass at the upper end of the room.

Emma. Yes, and I see Charles in it too.

Charles. I see Emma, but I do not see myself.

Father. This happens just like the marble which you shot sideways. The rays flow from Emma obliquely on the glass, upon which they strike, and fly off in a contrary direction, and by them you see her. I will apply this to sound.—If a bell *a* (Plate VII. Fig. 25.) be struck, and the undulations of the air strike the wall *c d* in a perpendicular direction, they will be reflected back in the same line; and if a person were properly situated between *a* and *c*, as at *x*, he would hear the sound of the bell by means of the undulations as they went to the wall, and he would

hear it again as they came back, which would be the echo of the first sound.

Emma. I now undertand the distinction between the direct sound and the echo.

Father. If the undulations strike the wall obliquely, they will, like the marble against the wainscot, or the rays of light against the glass, fly off again obliquely on the other side, in a reflected line, as *c m*: now if there be a hill or other obstacle between the bell and the place *m* where a person happens to be standing, he will not hear the direct sound of the bell, but only the echo of it, and to him the sound will come along the line *c m*.

Charles. I have heard of places where the sound is heard repeated several times.

Father. This happens where there are a number of walls, rocks, &c. which reflect the sound frome one to the other; and where a person happens to stand in such a situation as to intercept all the lines of reflection. These are called tautological or babbling echoes:

Babbling echo mocks the hounds,
Replying shrilly to the well-tun'd horns,
As if a double hunt were heard at once.

SHAKESPEARE.

There can be no echo unless the direct and reflected sounds follow one another at a sufficient interval of time; for if the latter arrive at the ear before the impression of the direct sound ceases, the sound will not be doubled, but only rendered more intense.

Emma. Is there any rule by which the time may be ascertained?

Father. Yes, there is; I will begin with the most simple case. If a person stand at x, (Plate VII. Fig. 25.) in order that the echo may be distinct, the *difference* between the space $a\ x$, and $a\ c$ added to $c\ x$, must be at least 127 feet.

Charles. The space through which the *direct* sound travels to a person is $a\ x$, and the whole direct line to the wall is $a\ c$, besides which it has to come back through

$c\ x$ to reach the pers-n again. All this I comprehend: but why do you say 127 feet in particular?

Father. It is founded on this principle. By experience it is known that about nine syllables can be articulately and distinctly pronounced in a second of time. But sound travels with the velocity of 1142 feet in a second, therefore in the ninth part of a second it passes over $\frac{1142}{9}$, or 127 feet nearly and consequently the reflected sound, which is the echo, to be distinct, must travel over at least 127 feet more than the direct.

Emma. If $c\ d$ in the figure represent the garden wall, how far must I be from it to hear distinctly any word I utter? will 63 or 64 feet be sufficient, so that the whole space which the sound has to travel be equal in this case also to 127 feet?

Father. It must be something more because the first sound rests a e on the ear, which should va-

nish before the echo returns, or it will appear a continuation of the former, and not a distinct sound: it is generally supposed that the distance must not be less than 70 or 72 feet; and this will give the distinct echo of one syllable only.

Charles. Must be distance be increased in proportion to the number of syllables that are to be repeated?

Father. Certainly; and at the distance of about 1000 or 1200 feet, eight or ten syllables, properly pronounced, will be distinctly repeated by the echo.

I will finish this subject to-morrow.

CONVERSATION XXXVI.

Of the Echo.

FATHER. The following are among the most celebrated echoes. At Rosneath, near Glasgow, there is an echo that repeats a tune played with a trumpet three times completely and distinctly. Near Rome there was one that repeated what a person said five times. At Brussels there is an echo that answers 15 times. At Thornbury Castle, Gloucestershire, an echo repeats 10 or 11 times very distinctly. Between Coblentz and Bingen an echo is celebrated as different from most others. In common echoes, the ... is not heard till some time after

hearing the words spoken or notes sung; in this the person who speaks or sings is scarcely heard, but the repetition is perceived very clearly, and in surprising varieties: the echo in some cases appears to be approaching, in others receding: sometimes it is heard distinctly, at others scarcely at all: one person hears only one voice, while another hears several. And to mention but one more instance, in Italy, near Milan, the sound of a pistol is returned 56 times.

Emma. This is indeed

To fetch shrill echoes from their hollow earth.

Father. The ingenious Mr. Derham applied the echo to measuring inaccessible distances.

Charles. How did he do this?

Father. Standing on the banks of the Thames, opposite Woolwich, he observed that the echo of a single sound was reflected from the houses in three seconds, conse-

quently in that time it had travelled 3426 feet, the half of which, or 1713 feet, was the breadth of the river in that particular place.

Did you ever hear of the Whispering-Gallery in the dome of St. Paul's Church:

Emma. Yes: and you promised to take us to see it some time.

Father. And I will peform my promise. In the mean time it may be proper to inform you, that the circumstance that attracts every person's attention is, that the smallest whisper made against the wall on one side of the gallery is distinctly heard on the other side.

Charles. Is this effect produced on the principle of the echo?

Father. No; the undulations caused in the air by the voice are reflected both ways round the wall, which is made very smooth, so that none may be lost, and meet at the opposite side; consequently, to the hearer, the sensation is the same as if his ear were close to the mouth of the speaker.

Emma. Would the effect be the same if the two persons were not opposite to one another?

Father. In that case the words spoken would be heard double, because one arch of the circle being less than the other, the sound will arrive at the ear sooner, round the shorter arch than round the longer one.

Charles. You said the wall is very smooth: is there a material difference, in the conveyance of sound, whether the medium be rough or smooth?

Father. The difference is very great. Still water is, perhaps, the best conductor of sound: the echo which I mentioned in the neighbourhood of Milan, depends much on the water over which the villa stands. Dr. Hutton in his Mathematical Dictionary, gives the following instance as a proof that moisture has a considerable effect upon sound. A house in Lambeth-marsh is very damp during winter, when it yields an echo, which abates as soon as it becomes dry in summer. To increase the sound in a the-

atre at Rome, a canal of water was carried under the floor, which caused a great difference.

After water, stone is reckoned a good conductor of sound, though the tone is rough and disagreeable: a well-made brick wall has been known to convey a whisper to the distance of 200 feet nearly. Wood is sonorous, and produces the most agreeable tone, and is therefore the most proper substance for musical instruments: of these we shall say a word or two before we quit the subject of sound.

Emma. All wind instruments, as flutes, trumpets, &c. must depend on the air: but do stringed instruments?

Father. They all depend on the vibrations which they make in the surrounding air. I will illustrate what I have to say by means of the Eolian harp.

If a cord eight or ten yards long be stretched very tight between two points, and then struck with a stick, the whole string

will not vibrate, but there will be several still places in it, between which the cord will move. Now the air acts upon the strings of the harp in the same manner as the stroke of the stick upon the long cord just mentioned.

Charles. Do not the different notes upon a violin depend upon the different length of the strings, which is varied by the fingers of the musician?

Father. They do; and the current of air acts upon each string, and divides it into parts, as so many imaginary bridges. Hence every string in an Eolian harp, though all are in union, become capable of several sounds, from which arises the wild and wonderful harmony of that instrument.

The undulations of the air, caused by the quick vibrations of a string, are well illustrated by a sort of mechanical sympathy that exists among accordant sounds. If two strings on different instruments are tuned in unison, and one be struck, the other will

reply though they be several feet distant from any one other.

Emma. How is this accounted for?

Father. The waves made by the first string, being of the same kind as would be made by the second if struck, those waves give a mechanical stroke to the second string, and produce its sound.

Charles. If all the strings on the Eolian harp are set to the same note, will they all vibrate by striking only one?

Father. They will: but the fact is well illustrated in this method: bend little bits of paper over each string, and then strike one sufficiently to shake off its paper, and you will see the others will fall from their strings.

Emma. Will not this happen if the strings are not in unison?

Father. Try for yourself, alter the notes of all the strings but two, and place the papers on again: vibrate that string which is in unison with another.

Emma. The papers on those are shaken off; but the others remain.

Father. A wet finger pressed round the edge of a thin drinking-glass will produce its key: if the glass be struck so as to produce its pitch, and an unison to that pitch be strongly excited on a violoncello, the glass will be set in motion, and if near the edge of the table, will be liable to be shaken off.

CONVERSATION XXXVIII.

Of the Winds.

FATHER. You know, my children, what the wind is.

Charles. You told us, a few days ago, that you should prove it was only the air in motion.

Father. I can show you in miniature, that air in motion will produce effects similar to those produced by a violent wind.

I place this little mill under the receiver of the air-pump in such a manner, that the air when re-entering may catch the vanes. I will exhaust the air;—now observe what happens when the stop-cock is opened.

Emma. The vanes turn round with an incredible velocity; much swifter than ever I saw the vanes of a real wind-mill. But what puts the air in motion, so as to cause the wind?

Father. There are, probably, many conspiring causes to produce the effect. The principal one seems to be heat communicated by the sun.

Charles. Does heat produce wind?

Father. Heat, you know, expands all bodies, consequently it rarefies the air, and makes it lighter. But you have seen that the lighter fluids ascend, and thereby leave a partial vacuum, towards which the surrounding heavier air presses, with a greater or less motion, according to the degree of rarefaction or of heat which produces it. The air of this room, by means of the fire, is much warmer than that in the passage.

Emma. Has that in the passage a tendency into the parlour?

Father. Take this lighted wax taper, and hold it at the bottom of the door.

Emma. The wind blows the flame violently into the room.

Father. Hold it now at the top of the door.

Charles. The flame rushes outwards there.

Father. This simple experiment deserves your attention. The heat of the room rarefies the air, and the lighter particles ascending, a partial vacuum is made at the lower part of the room; to supply the deficiency, the dense outward air rushes in, while the lighter particles, as they ascend, produce a current at the top of the door out of the room. If you hold the taper about the middle space between the bottom and top, you will find a part in which the flame is perfectly still, having no tendency either inwards or outwards.

The *smoke-jack*, so common in the chimneys of large kitchens, consists of a set of vanes, something like those of a wind-mill

or ventilator, fixed to wheel-work, which are put in motion by the current of air up the chimney, produced by the heat of the fire, and of course the force of the jack depends on the strength of the fire, and *not* upon the quantity of smoke, as the name of the machine would lead you to suppose.

Emma. Would you define the wind as a current of air?

Father. That is a very proper definition: and its direction is denominated from that quarter from which it blows.

Charles. When the wind blows from the north or south, do you say it is in the former case a north-wind, and in the latter a south-wind?

Father. We do. The winds are generally considered as of three kinds, independently of the names which they take from the points of the compass from which they blow. These are the *constant*, or those which always blow in the same direction: the *periodical*, or those which blow six months in one direction, and six in a contrary direc-

tion: and the *variable*, which appear to be subject to no general rules.

Emma. Is there any place where the wind always blows in one direction only?

Father. This happens to a very large part of the earth; to all that extensive tract that lies between 28 or 30 degrees north and south of the equator.

Charles. What is the cause of this?

Father. If you examine the globe, you will see* that the apparent course of the sun is from east to west, and that it is always vertical to some part of this tract of our globe; and since the wind follows the sun, it must, of necessity, blow in one direction constantly.

Emma. And is that due east?

Father. It is only so at the equator: for on the north of this line the wind declines

* It is supposed the reader is acquainted with the first volume of the Scientific Dialogues.

a little to the north point of the compass, and this the more so as the place is situated farther towards the north; on the south side the wind will be southerly.

Charles. The greater part of this tract of the globe is water; and I have heard you say, that transparent mediums do *not* receive heat from the sun.

Father. The greater part is certainly water: but the proportion of land is not small: almost the whole continent of Africa, a great part of Arabia, Persia, the East-Indies, and China, besides the whole nearly of New Holland, and numerous islands in the Indian and Pacific oceans: and in the western hemisphere, by far the greatest part of South America, New Spain, and the West-India islands, come within the limits of 30 degrees north and south of the equator. These amazingly large tracts of land imbibe the heat, by which the surrounding air, is rarefied, and thus the wind becomes *constant*, or blows in one direction.

You will also remember, that neither the

sea nor the atmosphere are so perfectly transparent as to transmit all the rays of the solar light; many are stopped in their passage, by which both the sea and air are warmed to a considerable degree. These constant or general winds are usually called *trade-winds*.

Emma. In what part of the globe do the *periodical* winds prevail?

Father. They prevail in several parts of the eastern and southern oceans, and evidently depend on the sun; for when the apparent motion of that body is north of the equator, that is, from the end of March to the same period in September, the wind sets in from the south-west; and the remainder of the year, while the sun is south of the equator, the wind blows from the north-east. These are called the monsoons, or shifting trade-winds, and are of considerable importance to those who make voyages to the East-Indies.

Charles. Do these changes take place suddenly?

Father. No: some days before and after the change there are calms, variable winds, and frequently the most violent storms.

On the greater part of the coasts situated between the tropics, the wind blows towards the shore in the day-time, and towards the sea by night. These winds are called sea and land breezes; they are affected by mountains, the course of rivers, tides, &c.

Emma. Is it the heat of the sun by day that rarefies the air over the land, and thus causes the wind?

Father. It is: the following easy experiment will illustrate the subject.

In the middle of a large dish of cold water put a water-plate filled with hot water; the former represents the ocean, the latter the land rarefying the air over it. Hold a lighted candle over the cold water, and blow it out; the smoke, you see, moves towards the plate. Reverse the experiment by filling the outer vessel with warm water, and the

plate with cold, the smoke will move from the plate to the dish.

Charles. In this country there is no regularity in the direction of the winds; sometimes the easterly winds prevail for several days together, at other times I have noticed the wind blowing from all quarters of the compass two or three times in the same day.

Father. The variableness of the wind in this island depends probably on a variety of causes; for whatever destroys the equilibrium in the atmosphere, produces a greater or less current of wind towards the place where the rarefaction exists.

It is generally believed that the electric fluid, which abounds in the air, is the principal cause of the variableness of the wind here. You may often see one tier of clouds moving in a certain direction, and another in a contrary one; that is, the higher clouds will be moving perhaps north or east, while the weather-cock stands directly south or west. In cases of this kind a sudden rare-

faction must have taken place in the regions of one set of these clouds, and consequently the equilibrium destroyed. This phenomenon is frequently found to precede a thunder-storm; from which it has been supposed that the electric fluid is, in this and such like instances, the principal cause in producing the wind: and if in the more remarkable appearances we are able to trace the operating cause, we may naturally infer that those which are less so, but of the same nature, depend on a like principle.

Emma. Violent storms must be occasioned by sudden and tremendous concussions in nature. I remember to have seen once last year (1800) some very large trees torn up by the wind. It is difficult to conceive how so thin and light a body can produce such dire effects.

Father. The inconceivable rapidity of lightning will account for the suddenness of any storm; and when you are acquainted with what velocity a wind will sometime

move, you will not be surprised at the effects which it is capable of producing.

Charles. Is there any method of ascertaining the velocity of the wind?

Father. Yes; several machines have been invented for the purpose. But Dr. Derham, by means of the flight of small downy feathers, contrived to measure the velocity of the great storm which happened in the year 1705, and he found that the wind moved 33 feet in half a second, that is, at the rate of 45 miles per hour: and it has been proved that the force of such a wind is equal to the perpendicular force of 10 pounds avoirdupois weight on every square foot. Now if you consider the surface which a large tree, with all its branches and leaves, presents to the wind, you will not be surprised, that, in great storms, some of them should be torn up by the root.

Emma. Is the velocity of 45 miles an hour supposed to be the greatest velocity of the wind?

Father. Dr. Derham thought the greatest velocity to be about 60 miles per hour. But we have tables calculated to show the *force* of the wind at all velocities from 1 to 100 miles per hour.

Charles. Does the *force* bear any general proportion to the velocity?

Father. Yes it does: the force increases as the *square* of the velocity.

Emma. Do you mean, that if on a piece of board, exposed to a given wind, there is a pressure equal to 1 pound, and the same board be exposed to another wind of *double* velocity, the pressure will be in this case 4 times greater than it was before?

Father. That is the rule. The following short table, selected from a larger one out of Dr. Hutton's Dictionary, will fix the rule and facts in your memory.

TABLE.

Velocity of the wind, in miles per hour.	Perpendicular force on one square foot in pounds avoirdupois.	Common appellation of the winds.
5	.123	Gentle, pleasant wind.
10	.492	Brisk Gale.
20	1.968	Very brisk.
40	7.872	Very high wind.
80	31.488	A Hurricane.

NOTE.—Mr. Brice discovered, from observations on the clouds, or their shadows moving on the surface of the earth, that the velocity of wind in a storm was nearly 63 miles in an hour, 21 miles in a fresh gale, and nearly 10 miles in a breeze.

CONVERSATION XXXVIII.

Of the Steam-Engine.

FATHER. If you understand the principle of the forcing-pump, you will easily comprehend in what manner the steam-engine, the most important of all hydrostatical machines, acts.

Charles. Why do you call it the most important of all machines? it is not a common one.

Father. Steam-engines can be used with advantage only in those cases where great power is required. They are adapted to the raising of water from ponds and

wells; to the draining of mines; and perhaps without their assistance we should not at this moment have the benefit of coal-fires.

Emma. Then there cannot be two opinions entertained respecting their utility. I do not know what we should do without them in winter, or even in summer, since coal is the fuel chiefly used in dressing our food.

Father. Our ancestors had, a century ago, excavated all the mines of coal as deep as they could be worked without the assistance of these sort of engines. For when the miners have dug a certain depth below the surface of the earth, the water pours in upon them from all sides; consequently they have no means of going on with their work without the assistance of a steam-engine, which is erected by the side of the pit, and being kept constantly at work, will keep it dry enough for all practical purposes.

The steam-engine was invented during

the reign of Charles II., though it was not brought to a degree of perfection sufficient for the draining of mines till nearly half a century after that period.

Charles. To whom is the world indebted for the discovery?

Father. It is difficult, if not impossible, to ascertain who was the inventor. The marquis of Worcester described the principle in a small work entitled "A century of inventions," which was published in the year 1663, and was reprinted a few years since in London.

Emma. Did the marquis construct one of these engines?

Father. No; the invention seems to have been neglected for several years, when captain Thomas Savery, after a variety of experiments, brought it to some degree of perfection, by which he was able to raise water, in small quantities, to a moderate height.

Charles. Did he take the invention from the marquis of Worcester's book?

Father. Dr. Desaguliers, who, in the middle of the last century, entered at large into the discussion, maintains that captain Savery was wholly indebted to the marquis, and to conceal the piracy, he charges him with having purchased all the books which contained the discovery, and burned them. Captain Savery, however, declared, that he was led to the discovery by the following accident :—" Having drank a flask of Florence wine at a tavern, and thrown the flask on the fire, he perceived that the few drops left in it were converted into steam; this induced him to snatch it from the fire, and plunge its neck into a bason of water, which by the atmospheric pressure, was driven quickly into the bottle."

Emma. This was something like an experiment which I have often seen at the tea-table. If I pour half a cup of water into the saucer, and then hold a piece of lighted paper in the cup a few seconds, and when the cup is pretty warm, plunge it with

the mouth downwards into the saucer, the water almost instantly disappears.

Father. In both cases, the principle is exactly the same: the heat of the burning paper converts the water that hung about the cup into steam, but steam being much lighter than air, expels the air from the cup, which being plunged into the water, the steam is quickly condensed, and a partial vacuum is made in the cup; consequently the pressure of the atmosphere upon the water in the saucer forces it into the cup, just in the same manner as the water follows the vacuum made in the pump.

Charles. Is steam, then, used for the purpose of making a vacuum, instead of a piston?

Father. Just so: and Dr. Darwin ascribes to captain Savery the honour of being the first person who applied it to the purpose of raising water:

Nymphs! you ere while on simmering caldrons
 play'd,
And call'd delighted SAVERY to your aid,
Bade round the youth EXPLOSIVE STEAM aspire
In gathering clouds, and wing'd the wave with
 fire:
Bade with cold streams the quick expansion stop,
And sunk the immense of vapour to a drop.
Press'd with the pond'rous air the piston falls
Resistless sliding through its iron walls;
Quick moves the balanc'd beam, of giant birth,
Wields his large limbs, and nodding shakes the
 earth.

Emma. I remember the lines very well: will you describe the engine, that we may see how they apply?

Father. I shall endeavour to give you a general and correct explanation of the principle and mode of acting of one of Mr. Watt's engines, without entering into all the minutiæ of the several parts.

A (Plate VIII. Fig. 35.) is a section of the boiler, standing over a fire, about half

full of water: B is the steam-pipe which conveys the steam from the boiler to the cylinder C, in which the piston D, made air-tight, works up and down, *a* and *c* are the steam valves, through which the steam enters into the cylinder; it is admitted through *a* when it is to force the piston downwards, and through *c* when it presses it upwards. *b* and *d* are the eduction valves, through which the steam passes from the cylinder into the condenser *e*, which is a separate vessel placed in a cistern of cold water, and which has a jet of cold water continually playing up in the inside of it. *f* is the air-pump, which extracts the air and water from the condenser. It is worked by the great beam or lever R S, and the water taken from the condenser, and thrown into the hot well *g*, is pumped up again by means of the pump *y*, and carried back into the boiler by the pipe *i i*. *k* is another pump, likewise worked by the engine itself, which

supplies the cistern, in which the condenser is fixed, with water.

Charles. Are all three pumps, as well as the piston, worked by the action of the great beam?

Father. They are; and you see the piston-rod is fastened to the beam by inflexible bars; but that the stroke might be perpendicular, Mr. Watt invented the machinery called the parallel joint, the construction of which will be easily understood from the figure.

Emma. How are the valves opened and shut?

Father. Long levers *o* and *p* are attached to them, which are moved up and down by the piston-rod of the air-pump E F. In order to communicate a rotatory motion to any machinery by the motion of the beam, Mr. Watt, makes use of a large fly-wheel X, on the axis of which is a small concentric toothed wheel H; a similar toothed wheel I is fastened to a rod T

coming from the end of the beam, so that it cannot turn on its axis, but must rise and fall with the motion of the great beam.

A bar of iron connects the centres of the two small toothed wheels; when therefore the beam raises the wheel I, it must move round the circumference of the wheel H, and with it turn the fly-wheel X; which will make two revolutions while the wheel I goes round it once. These are called the Sun and Planet wheels; H, like the sun, turns only on its axis, while I revolves about it as the planets revolve round the sun.

If to the centre of the fly-wheel any machinery were fixed, the motion of the great beam R S would keep it in constant work.

Charles. Will you describe the operations of the engine?

Father. Suppose the piston at the top of the cylinder, as it is represented in the plate, and the lower part of the cylinder filled with steam. By means of the pump-

rod, E F, the steam valve *a*, and the eduction valve *d* will be opened together, the branches from which being connected at *o*. There being now a communication at *d* between the cylinder and condenser, the steam is forced from the former into the latter, leaving the lower part of the cylinder empty, while the steam from the boiler entering by the valve *a* presses upon the piston, and forces it down. As soon as the piston has arrived at the bottom, the steam valve *c* and the eduction valve *b* are opened, while those at *a* and *d* are shut; the steam, therefore, immediately rushes through the eduction valve *b* into the condenser, while the piston is forced up again by the steam, which is now admitted by the valve *c*.*

* The author is obliged to Mr. LOWRY, engraver, and the proprietors of that interesting and useful periodical publication, entitled, "The Philosophical Magazine, comprehending the various Branches of Science," &c. &c. for the drawing of a steam-engine, which he has copied with some few alterations.

CONVERSATION XXXIX.

Of the Steam-Engine.

CHARLES. I do not understand how the two sets of valves act, which you described yesterday, as the steam and eduction valves.

Father. If you look to Fig. 30. Plate VIII. there is a different view of this part of the machine, unconnected with the rest: *s* is part of the pipe which brings the steam from the boiler, *a* represents the valve, which, being opened, admits the steam into the upper part of the cylinder, forcing down the piston.

Emma. Is not the valve *d* opened at the same time?

Father. It is: and then the steam which was under the piston is forced through into the condenser *e.* When the piston arrives at the bottom, the other pair of valves are opened, viz. *c* and *b*; through *c* the steam rushes to raise the piston, and through *b* the steam which pressed the piston down before, is driven out into the pipe *r*, leading to the condenser; in this there is a jet of cold water, constantly playing up, and thereby the steam is instantly reduced into the shape of hot water.

Charles. Then the condenser *e* (Fig. 35.) will soon be full of water.

Father. It would, if it were not connected by the pipe z with the pump *f*: and every time the great beam R S is brought down, the plunger, at the bottom of the piston rod E F, descends to the bottom of the pump.

Emma. Is there a valve in the plunger?

Father. Yes, which opens upwards, con-

sequently all the hot water which runs out of the condenser into the pump, will escape through the valve, and be at the top of the plunger, and the valve not admiting it to return, it will, by the ascent of the piston-rod into the situation as is shown in the plate, be driven through *n* into *g*, the cistern of hot water, from which, owing to a valve, it cannot return.

Charles. And I see the same motion of the great beam puts the pump *y* in action, and brings over the hot water from the cistern *g*, through the pipe *i i* into the little cistern v, which supplies the boiler.

Emma. If the pump *k* brings in, by the same motion the water from the well w, do not the hot and cold water intermix?

Father. No: if you look carefully in the figure, you will observe a strong partition v, which separates the one from the other. Besides, you may perceive that the hot water does not stand at so high a level as the cold, which is a sufficient proof that they do not communicate. Indeed

the operation of the engine would be greatly injured, if not wholly stopped, if the hot water communicated with the cold; as in that case the water, being at a medium heat, would be too warm to condense the steam in *e*, and too cold to be admitted into the boiler without checking the production of the sream.

Charles. There are some parts of the apparatus belonging to the boiler which you have not yet explained. What is the reason that the pipe *q*, which conveys the water from the cistern v to the boiler, is turned up at the lower end?

Father. If it were not bent in that manner the steam that is generated at the bottom of the boiler would rise into the pipe, and in a great measure prevent the descent of the water through it.

Emma. In this position I see clearly no steam can enter the pipe, because steam, being much lighter than water, must rise to the surface, and cannot possibly sink

through the bended part of the tube. What does *m* represent?

Father. It represents a stone suspended on a wire, which is shown by the dotted line; this stone is nicely balanced by means of a lever, to the other end of which is another wire, connected with a valve at the top of the pipe *q*, that goes down from the cistern.

Charles. Is the stone so balanced as to keep the valve sufficiently open to admit a proper quantity of water?

Father. It is represented by the figure in that situation. By a principle in hydrostatics,* with which you are acquainted, the stone is partly supported by the water; if then by increasing the fire, too great an evaporation take place, and the water in the boiler sink below its proper level, the stone also must sink, which will cause

* See Vol. II. Hyrostatics, Conversation XI.

the valve to open wider, and let that from the cistern come in faster. If, on the other hand, the evaporation be less than it ought to be, the water will have a tendency to rise in the boiler, and with that the stone must rise, and the valve will, consequently, let the water in with less velocity. By this neat contrivance the water in the boiler is always kept at one level.

Emma. What are the pipes *t* and *u* for?

Father. They are seldom used, but are intended to show the exact height of the water in the boiler. The one at *t* reaches very nearly to the surface of the water when it is at the proper height: that at *u* enters a little below the surface. If then the water be at its proper height, and the cocks *t* and *u* be opened, *steam* will issue from the *former*, and *water* from the *latter*. But if the water be too *high* it will rush out at *t* instead of steam: if two *low*, the steam will issue out of *u* instead of water.

Charles. Suppose things to be as repre-

sented in the plate, why will the waters rush out of the cock *u* if it be opened? it will not rise above its level.

Father. True: but you forget that there is a constant pressure of the steam on the surface of the water in the boiler which tends to raise the water in the pipe *u*. This pressure would force the water through the pipe, as in an artificial fountain see p. 73 and 74.

NOTE.—In the next conversation will be given an account of the purposes to which the steam-engine is applied. But perhaps one of the most striking exhibitions of the wonderful effects of this machine is to be seen in that part of the Portsmouth dockyard in which the blocks for ships are made. These blocks are completely finished from the rough timber, with scarcely any manual labour, by means of different saws and other tools worked by the steam-engine.

CONVERSATION XI.

Of the Steam-Engine, and Papin's Digester.

CHARLES. We have seen the structure of the steam-engine and its mode of operation; but you have not told us the uses to which it is applied.

Father. The application of this power was at first wholly devoted to the raising of water, either from the mines, which could not be worked without such aid, or to the throwing it to some immense reservoir, for the purpose of supplying, with this useful article, places which are higher than the natural level of the stream.

Emma. Is it to this that Dr. Darwin alludes in the lines,

> Here high in air the rising stream he pours,
> To clay-built cisterns, or to lead-lin'd towers;
> Fresh through a thousand pipes the wave distils,
> And thirsty cities drink th' exuberant rills.

Father. It is; and you might have repeated the whole passage, in which the steam-engine, represented as a giant-power, is supposed applicable to the bringing up of the coals, and other ore from the mine, and to the working of the bellows at the furnace, in which the ore is melted:

> Fan the white flame, and fuse the sparkling ore.

The author refers also to the application of this engine to various other purposes, such as the working of mills, the threshing of corn, and coining. In making the copper

money now in use, the ingenious Mr. Boulton has contrived, by a single operation of the steam-engine, to roll the copper out to a proper thickness, to cut it into circular pieces, and to make the faces and the edge.

Charles. How is the power of these engines estimated?

Father. The power varies according to the size. That at Messrs. Whitbread's brewhouse, to which I have had access through the kindness of Mr. Timothy Brown, a gentleman well known for his liberality, and attachment to men of science and literature, has a cylinder twenty-four inches in diameter, and will perform the work of twenty-four horses, working night and day.

Emma. But the horses cannot work incessantly.

Father. They will work only eight hours, at the average, out of the twenty-four, therefore since the engine is kept continually at work, it will perform the

business of seventy-two horses. The coals, consumed by this engine are about seven chaldrons per week, or one chaldron in twenty-four hours.

By the application of different machinery to this engine, it raises the malt into the upper warehouses, and grinds it; it pumps the wort from the under-backs into the copper; raises the wort into the coolers; it fills the barrels when the beer is made; and when the barrels are full and properly bunged, they are, by the steam-engine, driven into the store-houses in the next street, a distance of more than a hundred yards, and let down into the cellar.

Charles. I do not wonder then that Dr. Darwin should anticipate the still farther extension of this useful power:

Soon shall thy arm, *unconquered steam!* afar
Drag the slow barge, or drive the rapid car;
Or on wide waving wings expanded bear
The flying chariot through the fields of air.

Fair crews triumphant leaning from above,
Shall wave their fluttering kerchiefs as they move,
Or warrior-bands alarm the gaping crowd,
And armies shrink beneath the shadowy cloud.

Emma. Why does Dr. Darwin, in the passage you quoted the other day, call it *explosive* steam?

Father. From a great variety of accidents, that have happened through careless people, it appears that the expansive force of steam suddenly raised is much stronger than even that of gunpowder. At the cannon foundery in Moorfields, some years ago, hot metal was poured into a mould hat accidentally contained a small quantity of water, which was instantly converted into steam, and caused an explosion that blew the foundery to pieces. A similar accident happened at a foundery in Newcastle, which occurred from a little water having insinuated itself into a hollow brass ball that was thrown into the melting pot. These facts bring to my mind

a circumstance that I have often heard you relate, as coming within your knowledge.

Father. You do well to remind me of it. The fact is worth recording. A gentleman who was carrying on a long series of experiments, wished to ascertain the strength of a copper vessel, and gave orders to his workmen for the purpose. The vessel, however, burst unexpectedly, and in the explosion, it beat down the brick wall of the building in which it was placed, and was, by the force of the steam, carried fifteen or twenty yards from it; several of the bricks were thrown seventy yards from the spot; a leaden pipe suspended from an adjoining building, was bent into a right angle; and several of the men were so dreadfully bruised, or scalded, that for many weeks they were unable to stir from their beds. A very intelligent person, who conducted the experiment, assured me that he had not the smallest recollection how the accident hap-

pened, or by what means he got to his bed-room after it.

Emma. Is it by the force of steam that bones are dissolved in Papin's Digester, which you promised to describe?*

Father. No; that operation is performed by the great heat produced in the digester. Plate VII. Fig. 26. is a representation of one of these machines. It is a strong metal pot, at least an inch *thick* in every part; the top is screwed down, so that no steam can escape but through the valve V.

Charles. What kind of a valve is it?

Father. It is a conical piece of brass, made to fit very accurately, but easily moveable by the steam of the water when it boils: consequently in its simple state the heat of the water will never be much greater than that of boiling water in an open vessel. A steel-yard is therefore fitted

* See Vol. I. Of Mechanics Conversation III.

to it, and by moving the weight w backwards or forwards, the steam will have a lesser or greater pressure to overcome.

Emma. Is the heat increased by confining the steam?

Father. You have seen that, in an exhausted receiver, water not near so hot as the boiling point, will have every appearance of ebullition. It is the pressure of the atmosphere that causes the heat of boiling water to be greater in an open vessel, than in one from which the air is exhausted. In a vessel exposed to condensed air, the heat required to make the water boil would be still greater. Now by confining the steam, the pressure may be increased to any given degree. If, for instance, a force equal to 14 or 15 pounds be put on the valve, the pressure upon the water will be double that produced by the atmosphere, and of course the heat of the water will be greatly increased.

Charles. Is there no danger to be apprehended from the bursting of the vessel?

Father. If great care be taken not to load this valve too much, the danger is not very great. But in experiments made to ascertain the strength of any particular vessel, too great precautions cannot be taken.

Under the direction of Mr. Papin, the original inventor, the bottom of a digester, was torn off with a wonderful explosion: the blast of the expanded water blew all the coals out of the fire-place, the remainder of the vessel was hurled across the room, and striking the leaf of an oaken table an inch thick, broke it in pieces. The least sign of water could not be discerned, and every coal was extinguished in a moment.

CONVERSATION XLI.

Of the Barometer.

FATHER. As these conversations are intended to make you familiar with all those philosophical instruments that are in common use, as well as to explain the use and structure of those devoted to the teaching of science, I shall proceed with an account of the barometer, which with the thermometer are to be found in almost every house. I will show you how the barometer is made, without any regard to the frame to which it is attached.

A B (Plate VII. Fig. 27.) is a glass tube, about 33 or 34 inches long, closed at top;

that is, in philosophical language *hermetically sealed;* D is a cup, bason, or wooden trough, partly filled with quicksilver. I fill the tube with the quicksilver, and then put my finger upon the mouth, so as to prevent any of it from running out; I now invert the tube, and plunge it in the cup D. You see the mercury subsides three or four inches; and when the tube is fixed to a graduated frame, it is called a barometer, or weather-glass, and you know it is consulted by those who study and attend to the changes of the weather.

Emma. Why does not all the quicksilver run out of the tube?

Father. I will answer you, by asking another question: What is the reason that water will stand in an exhausted tube, provided the mouth of it be plunged into a vessel of the same fluid?

Charles. In that case the water is kept in the tube by the pressure of the atmosphere on the surface of the water into which it is plunged. If you resort to the same

principle, in the present instance, why does the water stand 33 or 34 *feet*, but the mercury only 29 or 30 inches?

Father. Do you not recollect that mercury is 14 times heavier than water, therefore if the pressure of the atmosphere will balance 34 feet of water, it ought, on the same principle, to balance only a 14th part of that height of mercury: now divide 34 feet, or 408 inches, by 14.

Emma. The quotient is little more than 29 inches.

Father. By this method Torricelli was led to construct the barometer. It had been accidentally discovered that water could not be raised more than about 34 feet in the pump if the piston exceeded that distance from the water. Torricelli, on this, suspected that the pressure of the atmosphere was the cause of the ascent of water in the vacuum made in pumps, and that a column of water 34 feet high was an exact counterpoise to a column of air which extended to the top of the atmosphere. Experiments soon con-

firmed the truth of his conjectures. He then thought, that if 34 feet of water were a counterpoise to the pressure of the atmosphere, a column of mercury, as much shorter than 34 feet as mercury is heavier than water, would likewise sustain the pressure of the atmosphere: he obtained a glass tube for the purpose, and found his reasoning just.

Charles. Did he apply it to the purpose of a weather-glass?

Father. No: it was not till some time after this that the pressure of the air was known to vary at different times in the same place. As soon as that was discovered, the application of the Torricellian tube to predicting ths changes of the weather immediately succeeded.

Charles. A barometer, then, is an instrument used for measuring the weight or pressure of the atmosphere.

Father. That is the principal use of the barometer: if the air be *dense* the mercury rises in the tube, and indicates fair

weather: if it grows *light*, the mercury falls, and presages rain, snow, &c.*

The height of the mercury in the tube is called the *standard altitude*, which in this country fluctuates between twenty-eight and thirty-one inches, and the difference between the greatest and least altitudes is called the *scale of variation*.

Emma. Is the fluctuation of the mercury different in other parts of the world?

Father. Within and near the tropics, there is little or no variation in the height of the mercury in the barometer in all weathers: this is the case at St. Helena. At Jamaica the variation very rarely exceeds three-tenths of an inch: at Naples it is about one inch: whereas in England it is nearly three inches, and at Petersburgh it is as much as 3½ inches.

Charles. The scale of variation is the

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* See the rules at the end of the volume.

silvered plate, which is divided into inches and tenths of an inch: but what do you call the moveable index?

Father. It is called a *vernier*, from the inventor's name, and the use of it is to show the fluctuation of the mercury to the hundredth part of an inch. The scale of inches is placed on the right side of the barometer tube, the beginning of the scale being the surface of the mercury in the bason: the vernier plate and index are moveable, so that the index may, at any time, be set to the upper surface of the column of mercury.

Emma. I have often seen you move the index, but I am still at a loss to conceive how you divide the inch into hundredth parts by it.

Father. The barometer-plate is divided into tenths; the length of the vernier is eleven tenths, but divided into ten equal parts.

Charles. Then each of the ten parts is

equal to a tenth of an inch, and a tenth part of a tenth.

Father. True: but the tenth part of a tenth is equal to a hundredth part, for you remember that to divide a fraction by any number is to multiply the denominator of the fraction by the number, thus $\frac{1}{10}$ divided by $10 = \frac{1}{100}$.

Suppose the index of the vernier to coincide exactly with one of the divisions of the scale of variation, as 29.3.

Emma. Then there is no difficulty; the height of the barometer is said to be 29 inches and 3 tenths.

Father. Perhaps, in the course of a few hours, you observe that the mercury has risen a very little, what will you do?

Emma. I will raise the vernier even with the mercury.

Father. And you find the index so much higher than the division three on the scale, as to bring the figure 1 on the vernier even with the second tenth on the scale.

Emma. Then the whole height is 29 inches 2 tenths, and one of the divisions on the vernier; which is equal to a tenth and a hundredth; that is, the height of the mercury is 29 inches, 3 tenths, and 1 hundredth, or 29.31.

Father. If figure 2 on the vernier stand even with a division on the scale, how should you call the height of the mercury?

Emma. Besides the number of tenths, I must add 2 hundredths, because each division of the vernier contains a tenth and a hundredth: therefore I say the barometer stands at 29.32; that is, 29 inches, 3 tenths, and 2 hundredths.

Father. Here is a representation A B (Plate VII. Fig. 28.) of the upper part of a barometer tube; the quicksilver stands at between A and C: from z to x is part of the scale of variation: 1 to 10 is the vernier, equal in length to $\frac{11}{10}$ths of an inch, but divided into ten equal parts. In [illegible] position of the mercury, the

figure 1 on the vernier coincides exactly with 29.5 on the scale; and finding the index stand between the sixth and seventh divisions on the scale, I therefore read the height 29.61; that is, 29 inches, 6 tenths, and 1 hundredth.

Charles. I now understand the principle of the barometer, but I want a guide to teach me how to predict the changes of the weather, which the rising and falling of the mercury presage.

Father. I will give you rules for this purpose in a few days.* Before we meet again, you may commit to your memory some lines beautifully descriptive of this instrument, and which include a just compliment to the memory of Torricelli and Boyle, both of whom are celebrated for their discoveries in this part of science:

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* See the end of the volume.

You charm'd indulgent SYLPHS! their learned toil,
And crown'd with fame your TORRICELL and BOYLE;
Taught with sweet smiles, responsive to their prayer,
The spring and pressure of the viewless air;
—How up exhausted tubes bright currents flow
Of liquid silver from the lake below;
Weigh the long column of th' incumbent skies,
And with the changeful moment fall and rise.

BOTANICAL GARDEN.

CONVERSATION XLII.

Of the Barometer, and its Application to the measuring of altitudes.

CHARLES. In those lines you gave us to learn, Dr. Darwin says, "Weigh the *long* column of the incumbent skies:" is the height of the atmosphere known?

Father. If the fluid air were similar to water, that is, every where of the same density, nothing would be easier than to calculate its height.—When the barometer stands at 30 inches, the specific gravity of the atmosphere is 800 times less than that of water;* but mercury is about 14 times heavier than water, consequently the speci-

* See Conversation XXVIII. of this volume.

fic gravity of mercury is to that of air as 800 multiplied by 14 is to 1; or mercury is 11,200 times heavier than air. In the case before us, a column of mercury, 30 inches long, balances the whole weight of the atmosphere; therefore, if the air were equally dense at all heights to the top, its height must be 11,200 times 30 inches; that is, the column of air must be as much longer than that of the mercury, as the former is lighter than the latter. Do you understand me?

Charles. I think I do: 11,200 multiplied by 30 gives 336,000 inches, which are equal to 5¼ miles nearly.

Father. That would be the height of the atmosphere if it were equally dense in all parts: but it is found that the air, by its elastic quality, expands and contracts, and that at 3½ miles above the surface of the earth it is as twice as rare as it is at the surface; that at 7 miles it is 4 times rarer; at 10½ miles it is 8 times rarer; at 14 miles it is 16 times rarer; and so on, according to ... ving.

TABLE.

At the altitude of	Miles above the surface of the earth, the air is		times lighter than at the earth's surface.
$3\frac{1}{2}$	-	2	
7	-	4	
$10\frac{1}{2}$	-	8	
14	-	16	
$17\frac{1}{2}$	-	32	
21	-	64	
$24\frac{1}{2}$	-	128	
28	-	256	

Now if you were disposed to carry on the addition on one side, and the multiplication on the other, you would find that at 500 miles above the surface of the earth, a single cubical inch of such air as we breathe, would be so much rarefied as to fill a hollow sphere, equal in diameter to the vast orbit of the planet Saturn.

Emma. Is it inferred from this that the atmosphere does not reach to any very great height?

Father. Certainly; for you have seen that a quart of air at the earth's surface

weighs but about 14 or 15 grains; and by carrying on the above table a few steps, you would perceive, that the same quantity, only 49 miles high, would weigh less than the 16 thousandth part of 14 grains, consequently at that height its density must be next to nothing. From experiment and calculation it is generally admitted, that the atmosphere reaches about 45 or 50 miles above the earth's surface.

Charles. By comparing the state of the atmosphere at the bottom and at the top of a mountain, should you perceive a sensible difference?

Father. We must not trust to our feelings on such occasions. The barometer will be a sure guide. I will not trouble you with calculations, but mention two or three facts, with the conclusions to be drawn from them. In ascending the Puy de Domme, a very high mountain in France, the quicksilver fell $3\frac{1}{2}$ inches; and the height of the mountain was found, by measurement, to be 3204 feet. By a similar experiment upon

Snowden, in Wales, the quicksilver was found to have fallen $3\frac{8}{10}$ inches at the height of 3720 feet above the surface of the earth.

From these and many other observations it is inferred, that in ascending any lofty eminence, the mercury in the barometer will fall $\frac{1}{10}$ of an inch for every 100 feet of perpendicular ascent. This number is not rigidly exact, but sufficiently so for common purposes, and it will be easily remembered. The three following observations were taken by Dr. Nettleton near the town of Halifax:

Perpendicular altitude in feet.	Lowest station of the Barometer.	Highest station of the Barometer.	Difference.
102	29.78	29.66	0.12
236	39.50	29.23	0.27
507	30.00	29.45	0.55

Emma. If I ascend a high hill, and, taking a barometer with me, find the mercury has fallen $1\frac{1}{2}$ inch, may I not conclude that the hill is 1500 feet perpendicular height?

Father. You may. Are you aware how great a pressure you are continually sustaining?

Emma. No; it never came into my head. I feel no burden from it, therefore it cannot be very great.

Father. You sustain every moment a weight equal to many tons, which if it were not balanced by the elastic force of the air within the body, would crush you to pieces; this is well described by Mr. Lofft.

> *Internal* balancing *external* force,
> Remove the external, and, to atoms torn,
> Our dissipated limbs would strew the earth:
> Remove the internal, in a moment crush'd
> By greater weight of the incumbent air,
> Than rocks by fabled giants ever thrown.
>
> *Eudosia.*

Charles. We might indeed have inferred that it was considerable from the sensations that we felt when the air was taken from under our hands. But how, Sir, do you make out the assertion?

Father. When the barometer stands at 29.5 the pressure of the air upon every square inch is more than equal to 14 pounds; call it 14 pounds for the sake of even num-

ben, and the surface of a middle sized man is 14½ feet; tell me now the weight he sustains.

Charles. I must multiply 14 by the number of square inches in 14½ feet: now there are 144 inches in a square foot, consequently in 14½ feet there are 2088 square inches; therefore 14 pounds multiplied by 2088 will give 29,232, the number of pounds-weight pressing upon such a person.

Father. That is equal to about 13 tons; now if Emma reckons herself half only the size of a grown person, the pressure upon her will be equal to 6½ tons.

Emma. What must the pressure upon the whole earth be?

Father. This you may calculate at your leasure, I will furnish you with the rule.

"Find the diameter of the earth,* from which you will easily get the superficial measure in square inches, and this you must multiply by 14, and you get the an-

* See Vol. I. Conversation. VII. Note, p. 52.

swer to the question in pounds avoirdupois."

The earth's surface contains about 200,000,000 square miles; and as every square mile contains 27,876,400 square feet, there must be 5,575,280,000,000,000 square feet in the earth's surface, which number multiplied by the pressure on each square foot, gives the whole weight of the atmosphere.

CONVERSATION XLIII.

Of the Thermometer.

FATHER. As the barometer is intended to measure the different degrees of density of the atmosphere, so the thermometer is designed to mark the changes in its temperature, with regard to heat and cold.

Emma. Is there any difference between the thermometer that is attached to the barometer, and that which hangs out of doors?

Father. No; they are both made by the same person, and are intended to show

the same effects. But for the purposes of accurate observation, it is usual to have two instruments, one attached to, or near the barometer, and the other out of doors, to which neither the direct nor reflected rays of the sun should ever come. Though my thermometers are both of the same construction, and such as are principally used in this country, yet there are others made of different materials and upon different principles.

Charles. Does not this thermometer consist of mercury enclosed in a glass tube which is fixed to a graduated frame?

Father. That is the construction of Fahrenheit's thermometer: but when these instruments were first invented, about two hundred years ago, air, water, spirits of wine, and then oil, were made use of; but these have given way to quicksilver, which is considered as the best of all the fluids, being highly susceptible of expansion and contraction, and capable of exhibiting a more extensive scale of heat.

Fahrenheit's thermometer is chiefly used in Great Britain, and Reaumur's on the Continent.

Emma. Is not this the principle of the thermometer, that the quicksilver expands by heat, and contracts by cold?

Father. It is: place your thumb on the bulb of the thermometer.

Emma. The quicksilver gradually rises.

Father. And it will continue to rise till the mercury and your thumb are of equal heat. Now you have taken away your hand, you perceive the mercury is falling as fast as it rose.

Charles Will it come down to the same point at which it stood before Emma touched it?

Father. It will, unless, in this short space of time, there has been any change in the surrounding air. Thus the thermometer indicates the temperature of the air, or, in fact, of any body with which it is in contact. Just now it was in contact

with your thumb, and it rose in the space of a minute or two from 56° to 62°; had you held it longer on it, the mercury would have risen still higher. It is now falling. Plunge it into boiling water,* and you will find that the mercury rises to 212°. Afterwards you may, when it is cool, place it in ice, in its melting state, and it will fall to 32°.

Emma. Why are these particular numbers pitched on?

Father. You will not perhaps be satisfied if I tell you, that the only reason why 212 was fixed on to mark the heat of boiling water, and thirty-two that to show the freezing point, was, because it so pleased M. Fahrenheit: this, however, was the case.

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* This should be done very gradually, by holding it some time in the steam, to prevent its breaking by the sudden heat.

Charles. I can easily conceive that at the same degree of cold, water will always begin to freeze; but surely there are different degrees of heat in boiling water, and therefore it should seem strange to have only one number for it.

Father. In an open vessel, boiling water is always of the same heat, that is, provided the density of the atmosphere be the same; and though you increase your fire in a tenfold proportion, yet the water will never be a single degree hotter; for the superabundant heat, communicated to the water, flies off in the form of steam or vapour.

Emma. But suppose you confine the steam.

Father. Before I should attempt this I must be provided with a strong vessel, or, as you have seen under the article of the steam-engine, it would certainly burst. But in a vessel proper for the purpose, water has been made so hot as to melt solid lead.

Charles. Will you explain the construction of the thermometer?

Father. A B (Plate VII. Fig. 29.) represents a glass tube, the end A is blown into a bulb, and this, with a part of the tube, are filled with mercury. In good thermometers, the upper part of the tube approaches to a perfect vacuum, and of course the end B is hermetically sealed. If the tube be now placed in pounded ice, the mercury will sink to a certain point x, which must be marked on the tube, and on the scale opposite to this point 32 must be placed, which is called the freezing point. Then let it be immersed in boiling water, the mercury will rise, and, after a few minutes become stationary. Against that point make another mark, and write on the scale 212 for the heat of boiling water. Between these points let the scale be divided into 180 equal parts.

Emma. Why 180 parts?

Father. Because you begin from 32, and if you subtract that number from 212, the remainder will be 180. Also below 32, and above 212, set off more divisions on the ... to the others. The scale is fi-

nished when you have written against 0 *extreme cold*, against 32 *freezing point*, against 55 *temperate heat*, against 76 *summer heat*, against 98 *blood heat*, against 112 *fever heat*, against 176 *spirits boils*, and against 212 *water boils*.

Emma. You said the scale was to be divided higher than boiling water, but without mentioning the extent.

Father. The utmost extent of the *mercuiral* thermometer both ways, are the points at which quicksilver boils and freezes; beyond these it can be no guide: now the degree of heat at which mercury boils is 600 and, it freezes when it is brought down as low as 39° or 40° below 0; consequently the whole extent of the mercurial thermometer is 640 degrees.

CONVERSATION XLIV.

Of the Thermometer.

CHARLES. Is quicksilver, when frozen, a solid metal, like iron and other metals?

Father. It is thus far similar to them, that it is malleable, or will bear hammering. And when the quicksilver boils, it goes off in vapour like boiling water, only much slower. Hence it has been inferred, that all bodies in nature are capable of existing either in a *solid*, *fluid*, or *aeriform* state, according to the degree of heat to which they are exposed.

Emma. I understand that water may be either solid as ice, or in its fluid *natural state*, or in a state of vapour or stream.

Father. I do not wonder that you call the fluid state of water its natural state, because we are accustomed, in general, to see it so; and when it is frozen into ice, there appears to us, in this country, a violence committed upon nature. But if a person from the West or East-Indies, who had never seen the effects of frost, were to arrive in Great Britain during a severe and long continued one, such as formerly congealed the surface of the Thames, unless he were told to the contrary, he would conclude that ice was some mineral, and naturally solid.

Emma. Does it never freeze in the East or West Indies?

Father. It seldom freezes, unless in very elevated situations, within 35 degrees of the equator north and south: it scarcely ever hails in latitude higher than 60°. In our own climate, and indeed in all others between 35° and 60°, it rarely freezes till the

sun's meridian altitude is less than 40 degrees. The coldest part of the 24 hours is generally about an hour before sun rise, and the warmest part of the day is usually between two and four o'clock in the afternoon.

Charles. Are there no degrees of heat higher than that of boiling mercury?

Father. Yes, a great many: brass will not melt till it is heated more than six times hotter than boiling mercury; and to melt cast-iron requires a heat more than six times greater than this.

Emma. By what kind of thermometer are these degrees of heat measured?

Father. The ingenious Mr. Wedgewood has invented a thermometer for measuring the degrees of heat up to 32277° of Fahrenheit's scale.

Charles. Can you explain the structure of his thermometer?

Father. All argillaceous bodies, or bodies made of clay, are diminished in bulk by the application of great heat. The diminution commences in a dull red heat, and pro[illegible]gularly as the heat increases till

the clay is vitrified, or transformed into a glassy substance. This is the principle of Mr. Wedgewood's thermometer.

Emma. Is vitrification the limit of this thermometer?

Father. Certainly. The construction and application of this extremely simple, and it marks all the different degrees of ignition from the red heat, visible only in the dark, to the heat of an air furnace. It consists of two rulers fixed on a plane, a little farther asunder at one end than at the other, leaving a space between them. Small pieces of alum and clay, mixed together, are made just large enough to enter at the wide end: they are then heated in the fire with the body whose heat is to be ascertained. The fire, according to its heat, contracts the earthy body, so that being applied to the wide end of the guage, it will slide on towards the narrow end, less or more, according to the degree of heat to which it has been exposed.*

* We have in the former parts of this work observed, that all bodies are expanded by heat. The diminution

Each degree of Mr. Wedgewood's thermometer answers to 130 degrees of Fahrenheit, and he begins his scale from red heat fully visible in day-light, which he finds to be equal to 1077° of Fahrenheit's scale, if it could be carried so high.

In the next page is a small scale, of heat as it is applicable to a few bodies.

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of the argillaceous substances made use by Mr. Wedgewood *appears* to be an exception: but as the contraction of these does not commence till they are exposed to a red heat, it may probably be accounted for, from the expulsion of the fluid particles, rather than from any real contraction in the solids.

SCALE OF HEAT.

	Wedgwood		Fahrenheit.
Extremity of Wedge-Wood's scale .	240°	which answers to	32277°
Cast iron melts . . at	160	which answers to	21877
Fine gold melts . —	32	which answers to	5237
Fine silver melts . —	28	which answers to	4717
Brass melts . . . —	21	which answers to	3807
Red heat visible by day	0	which answers to	1077
Mercury boils . . . . at			600
Lead melts .		*Note.* If these three metals be mixed together by fusion in the proportion of 5, 8, and 3, the mixture will melt in a heat below that of boiling water.	at 540
Bismuth melts.			— 460
Tin melts .			— 408
Milk boils . . . . at			213
Water boils . . . . —			212
Heat of the human body . . . . —			92 to 97
Water freezes . . . . —			32
Milk freezes . . . . —			30
A mixture of snow and salt sinks the thermometer to			0
Mercury freezes			—40°

Charles. The bar cannot expand without moving the index F H, the crooked part of which pressing upon L S, that also will be moved if the bar lengthens.

Father. Try the experiment; friction, you know, produces heat; take the bar out of the nuts, rub it briskly, and then replace it.

Emma. The index L S has moved to that part of the scale which is marked 2, it is now going back: How do you calculate the length of the expansion?

Father. The bar pressed against the index F H at F, and that again presses against L S at Z, and hence they both act as levers.

Charles. And they are levers of the third kind, for in one case the fulcrum is at x, the power at F, and the point Z to be moved may be considered as the weight: —in the other, L is the fulcrum, the power is applied at Z, and the point S is to be moved.*

' account of the different levers, see Vol. I. XV. and XVI.

Father. The distance between the moving point F and H is 20 times greater than that between x and F; the same proportion holds between L S and L Z, from this you will get the spaces passed through by the different points.

Emma. Then as much as the iron bar expands, so much will it move the point F, and of course the point Z will move 20 times as much; so that if the bar lengthen $\frac{1}{10}$th of an inch, the point Z would move $\frac{20}{10}$ths, or 2 inches. By the same rule the point S will move through a space 20 times as great as the point Z.

Father. There are two levers then, each of which gain power, or move over spaces in the proportion of 20 to 1; consequently, when united as in the present case, into a compound lever, we multiply 20 into 20, which make 400; and therefore if the bar lengthen $\frac{1}{10}$th of an inch, the point S must move over 400 times that space, or 40 inches. But suppose it only expands $\frac{1}{100}$th part of an inch, how much will S move?

Charles. One inch.

Father. But every inch may be divided into tenths, and consequently if the bar lengthen only the $\frac{1}{4000}$th part of an inch, the point s will move through the tenth part of an inch, which is very perceptible. In the present case the point s has moved two inches, therefore the expansion is equal to $\frac{2}{400}$ths, or $\frac{1}{200}$th part of an inch. —An iron bar, three feet long, is about $\frac{1}{70}$th part of an inch longer in summer than in winter.

Charles. I see that by increasing the number of levers, you might carry the experiment to a much greater degree of nicety.

Father. Well, let us now proceed to the hygrometer, which is an instrument contrived for measuring the different degrees of moisture in the atmosphere.

Emma. I have a weather-house that I bought at the fair, which tells me this; for if the air is very moist, and thereby denotes

wet weather, the man comes out; and in fair weather, when the atmosphere is dry, the woman makes her appearance.

Charles. How is the weather-house constructed?

Father. The two images are placed on a kind of lever, which is sustained by catgut; and catgut is very sensible to moisture, twisting and shortening by moisture, and untwisting and lengthening as it becomes dry. On the same principle is constructed another hygrometer. A B (Plate VII. Fig. 31.) is a catgut string, suspended at A with a little weight B, that carries an index C round a circular scale D E on a horizontal board or table: for as the catgut becomes moist, it twists itself, and untwists when it approaches to a dry state.

Emma. Then the degrees of moisture are shown by the index, which moves backwards and forwards by the twisting and untwisting of the catgut. Does all strings twist with moisture.

Father. Yes. Take a piece of common packthread, and on it suspend a pound weight in a vessel of water, and you will see how soon the two strings are twisted round one another.

Charles. I recollect that the last time the lines for drying the linen were hung out in the garden, they appeared to be much looser in the evening than they were next morning, so that I thought some person had been altering them. A sudden shower of rain has produced the same effect in a striking manner.

Emma. Sometimes, when sudden damp weather has set in, the string of the harp has snapped when no person has been near it.

Father. These are the effects produced by the moisture of the air; the damp of night always shortens hair and hempen lines; and, owing to the changes to which the atmosphere in our climate is liable, the harp, violin, &c. that are set to tune one

day, will need some alteration before they can be used the next.

Here is a sensible and very simple hygrometer: it consists of a piece of whipcord, or catgut (Plate VII. Fig. 32,) fastened at A, and stretched over several pulleys, B, C, D, E, F; at the end is a little weight W, to which is an index pointing to a graduated scale.

Charles. Then according to the degree of moisture in the air, the string shortens or lengthens, and of course the index points higher or lower.

Father. Another kind of hygrometer consists of a piece of sponge E (Plate VII. Fig. 33.) prepared and nicely balanced on the beam *x y;* and the fulcrum *z* lengthened out into an index pointing to a scale A C.

Emma. Does the sponge imbibe moisture sufficiently to become a good hygrometer?

Father. Sponge of itself will answer

the purpose, but it is made much more sensible in the following manner:

After the sponge is well washed from all impurities and dried again, it should be dipped into water or vinegar in which sal-ammoniac, salt of tartar, or almost any other saline substance, has been dissolved, and then suffered to dry, when it should be accurately balanced.

Charles. Do the saline particles, in damp weather, imbibe the moisture, and cause the sponge to preponderate?

Father. They do. Instead of sponge a scale may be hung at E, in which must be put some kind of salt that has an attraction to the watery particles floating in the air. Sulphuric acid may be substituted in the place of salt, but this is not fit for your experiments, because a little spilt over will destroy your clothes. otherwise it makes a very sensible hygrometer.

Emma. I have heard the cook com-

plain of the damp weather when the salt becomes wet by it.

Father. Right: the salt box in the kitchen is not a bad hygrometer.

Note.—The ratio of expansion of metallic rods of the same diameter, placed in boiling water, is found to be in brass 94, iron 73, lead 154, and silver 81.

CONVERSATION XLVI.

Of the Rain-Gauge.

CHARLES. Does the rain-gauge measure the quantity of rain that falls?

Father. It shows the height to which the rain would rise on the place where it is fixed, if there were no evaporation, and if none of it were imbibed by the earth. One which is made and sold by Mr. Jones, of Holborn, consists of the funnel A (Plate VII. Fig. 34.) communicating with a cylindric tube B. The diameter of the funnel is exactly 12 inches, that of the tube is 4 inches Tell me, Emma, what proportion the area of the former has to that of the latter.

Emma. I remember that all plane surfaces bear the same proportion to one another that the squares of their diameters have. Now the square of 12 is 144, and the square of 4 is 16, therefore the proportion of the area of the funnel is to that of the tube as 144 to 16.

Father. But 144 may be divided by 16 without leaving a remainder.

Charles. Yes; 9 times 16 is 144, consequently the proportion is as 9 to 1; that is, the area of the funnel is 9 times greater than that of the tube.

Father. If then the water in the tube be raised 9 inches, the depth of rain fallen will in the area of the funnel, which is the true guage, be only one inch.

Emma. Does the little graduated rule mark the rise?

Father. Yes, it does. It is a floating index divided into inches.

Emma. If then the float be raised 1 inch, is the depth of water reckoned only $\frac{1}{9}$ of an inch?

Father. Just so: and each nine inches in length being divided into 100 equal parts, the fall of rain can be readily estimated to the $\frac{1}{100}$th part of an inch. Rain-gauges should be varnished or well painted, and as much water should be first poured in as will raise the float to such a height, *that* 0 or zero on the ruler may coincide *with* the edge of the funnel.

Charles. This is not like your rain gauge.

Father. That which I use, though somewhat more difficult of explanation, is a much cheaper instrument; it may without the bottle be made for a single shilling. It consists of a tin or copper funnel; the area of the top contains exactly 10 square inches, and the tube, about 5 or 7 inches long, passes through a cork that is fixed in a quart bottle.

Emma. Is there any particular proportion between the area of the funnel and that of the bottle?

Father. No, it is not necessary; for in this, the quantity of the rain is calculated by [illegible]ght compared with the area of the fun-

nel, which is known. For every ounce of water I allow .173 parts of an inch for the depth of the rain fallen. Thus the last time that I examined the bottle, I found that the water weighed exactly six ounces, and 6 multiplied by .173 gives 1.038; that is, the rain fallen in the preceding month was equal to rather more than 1 inch in depth. In the month of June (1801) the rain collected in the gauge weighed 11½ ounces, which is nearly equal to 2 inches in depth.

Charles. Pray explain the reason of multiplying the number of ounces by the decimal .173.

Father. Every gallon of pure rain water contains 231 cubic inches, and weighs 8 lb. 5 oz. ⅔ avoirdupois, or 133.66 ounces; consequently every ounce of water is equal to $231 \div 133.\dot{6}6 = 1.73$ cubic inches; but the area of the funnel is 10 square inches, therefore $1.73 \div 10 = 173$ gives the depth of rain fallen for every cubic inch of water collected, or for every ounce in the gauge.

You have now a pretty full account of all the instruments necessary for judging of the

state of the weather, and for comparing, at different seasons, the various changes as they happen.

Emma. Yes; the *barometer* informs us how *dense* the atmosphere is; the *thermometer* enables us to ascertain its heat; the *hygrometer* what degree of *moisture* it contains; and by the *rain-gauge* we learn how much rain falls in a given time.

Father. The rain-gauge must be fixed at some distance from all buildings, which might in any way shelter it from particular driving winds; and the height at which the surface of the funnel is from the ground must be ascertained.

Charles. Does it make any difference in the quantity of rain collected whether the gauge stands on the ground, or some feet above it?

Father. Very considerable: as that which I have described is a cheap instrument, one may be placed on the top of the house, and the other on the garden-wall, and you will find the difference much greater than you would imagine.—I will now give you ... for judging of, and predicting,

the state of the weather, which are taken from writers who have paid the most attention to these subjects, and which my own observations have verified.

1. The rising of the mercury presages, in general, fair weather, and its falling foul weather, as rain, snow, high winds, and storms. When the surface of the mercury is convex, or stands higher in the middle than at the sides, it is a sign the mercury is then in a rising state; but if the surface be concave or hollow in the middle, it is then sinking.

2. In very hot weather, the falling of the mercury indicates thunder.

3. In winter, the rising presages frost: and in frosty weather, if the mercury falls three or four divisions, there will be a thaw. But in a continued frost, if the mercury rises, it will certainly snow.

4. When wet weather happens soon after the depression of the mercury, expect but little of it; on the contrary, expect but little fair weather when it proves fair shortly after the mercury has risen.

5. In wet weather, when the mercury ri-

ses much and high, and so continues for two or three days before the bad weather is entirely over, then a continuance of fair weather may be expected.

6. In fair weather when the mercury falls much and low, and thus continues for two or three days before the rain comes, then a deal of wet may be expected, and probably high winds.

7. The unsettled motion of the mercury denotes unsettled weather.

8. The words engraved on the scale are not so much to be attended to as the rising and falling of the mercury: for if it stand at *much rain*, and then rises to changeable, it denotes fair weather, though not to continue so long as if the mercury had risen higher. If the mercury stands at fair, and falls to changeable, bad weather may be expected.

9. In winter, spring, and autumn, the sudden falling of the mercury, and that for a large space, denotes high winds and storms; but in summer it presages heavy showers, and often thunder. It always sinks lowest [illegible] winds, though not accompa-

nied with rain; but it falls more for wind and rain together than for either of them alone.

10. If after rain the wind change into any part of the north, with a clear and dry sky, and the mercury rise, it is a certain sign of fair weather.

11. After very great storms of wind, when the mercury has been low, it commonly rises again very fast. In settled fair weather, except the barometer sink much, expect but little rain. In a wet season, the smallest depressions must be attended to; for when the air is much inclined to showers, a little sinking in the barometer denotes more rain. And in such a season, as if it rise suddenly fast and high, fair weather cannot be expected to last more than a day or two.

12. The greatest heights of the mercury are found upon easterly and north-easterly winds; and it may often rain or snow, the wind being in these points, while the barometer is in a rising state, the effects of the wind counteracting. But the mercury sinks for wind as well as rain in all other points of the compass.

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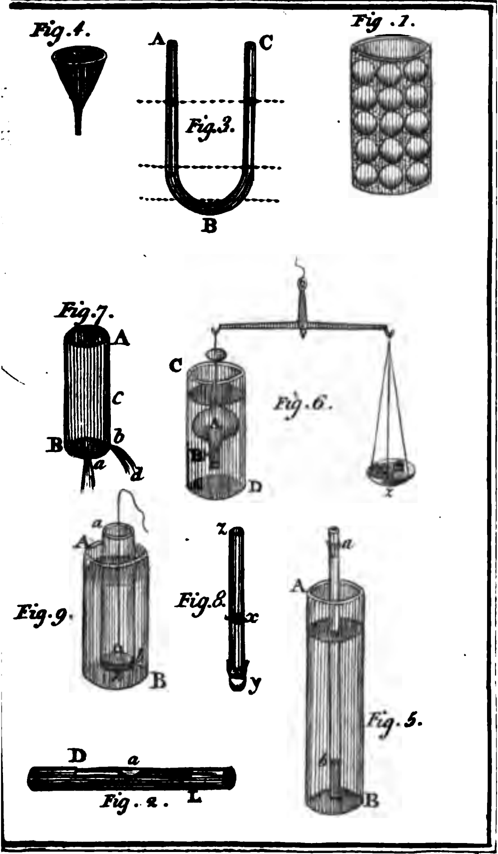
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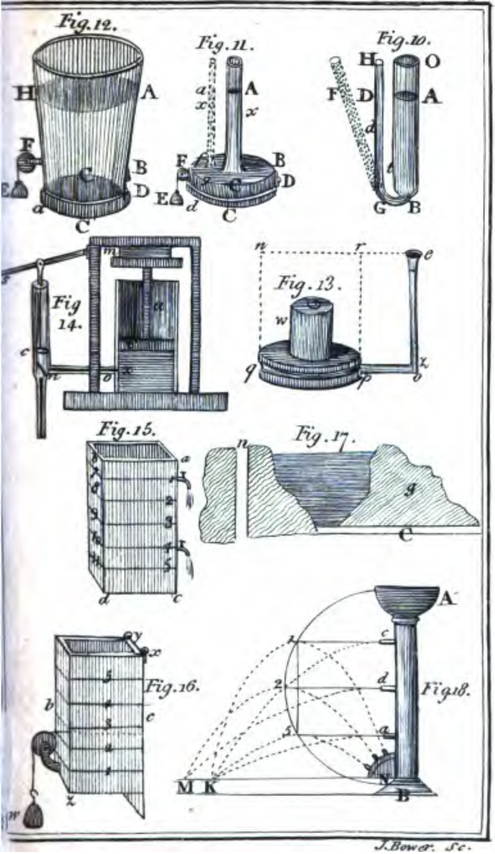
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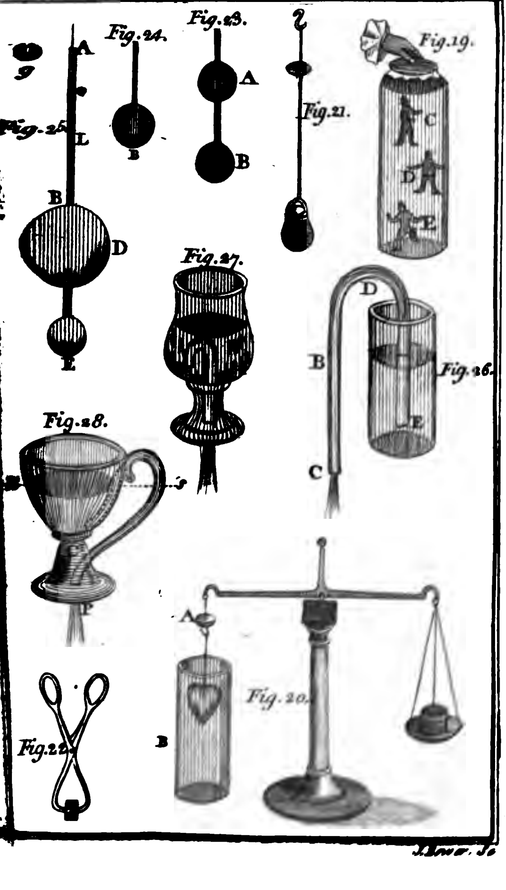
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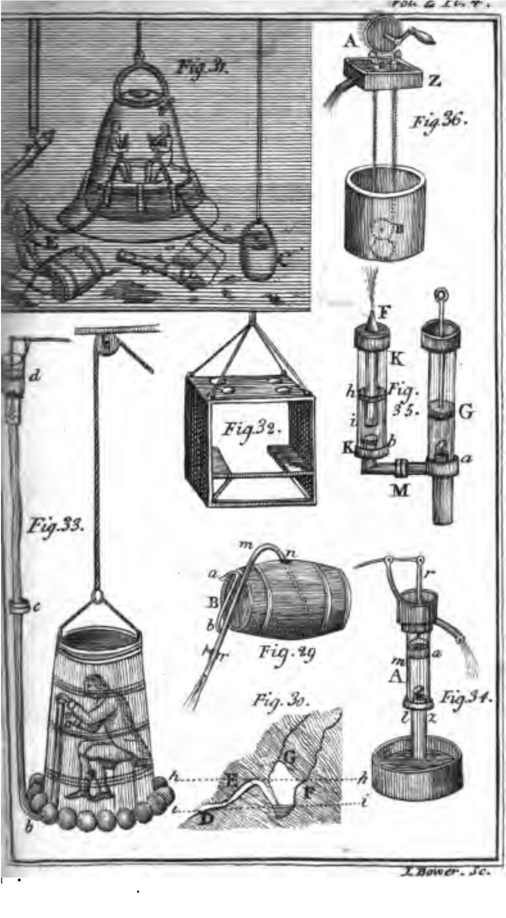

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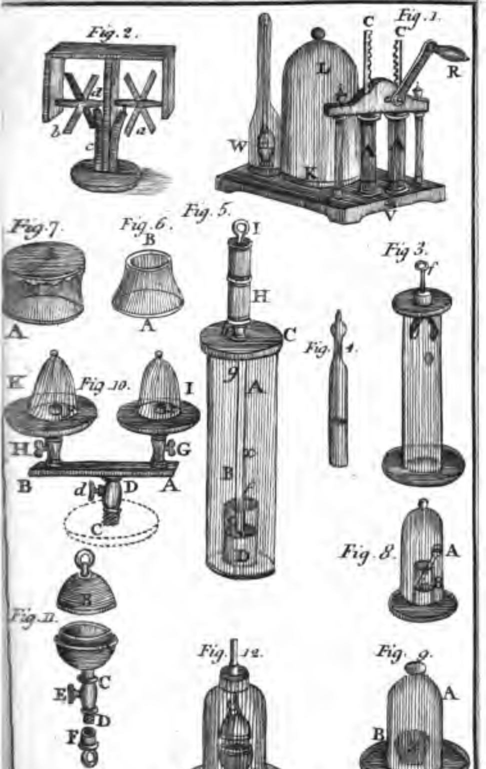
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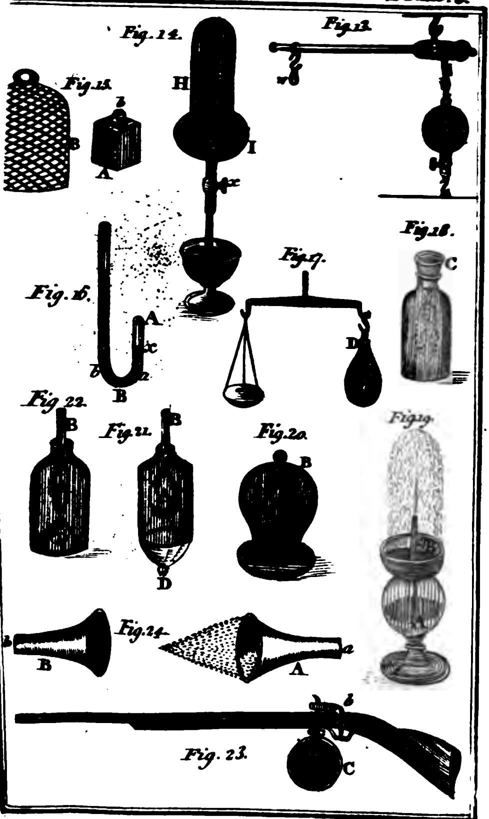
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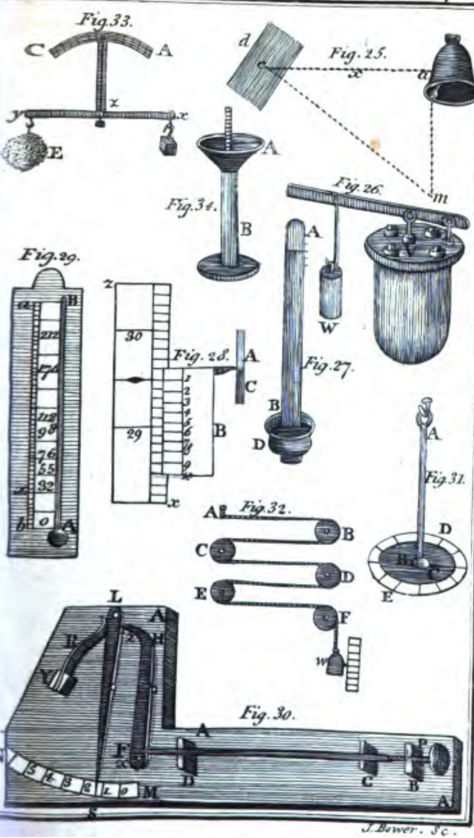
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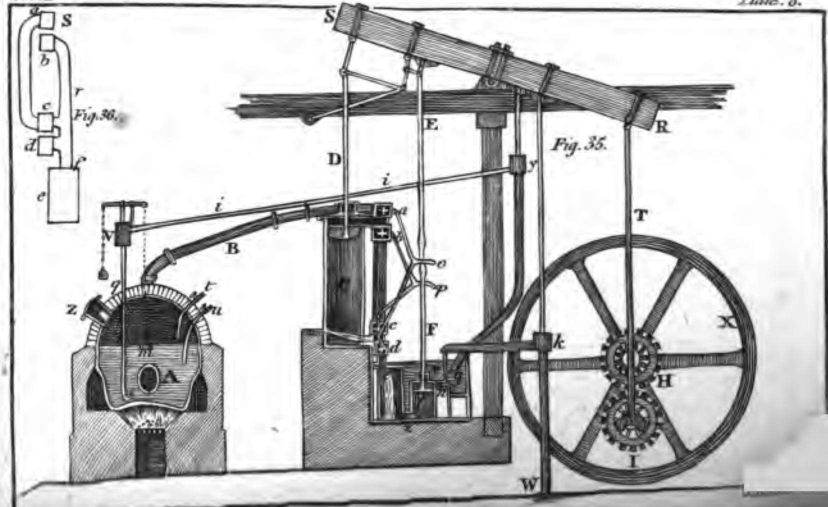

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